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DIFFUSION OF PARTICLES BY TURBULENCE: EFFECT OF PARTICLE SIZE

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by Hirendra Majumdar and M. R. Carstens

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Federal Water Pollution Control Administration
Department of the Interior

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By

HIRENDRA MAJUMDAR AND M. R. CARSTENS

Final Report

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SCHOOL OF CIVIL ENGINEERING
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FOREWORD

The work performed in this study was made possible by virtue of a grant from the Federal Water Pollution Control Administration, Department of the Interior (Grant No. 5 R01 WP 00912-02 ESE). The financial support is gratefully acknowledged.

The first author was responsible for performing the experiments and for data reduction. The second author served as project director. In this report the extensive data (APPENDIX A) were used to determine the usual parameters associated with diffusion. The same data are being used in the first author's Ph.D. dissertation in detailed analysis of the motion within the diffusion chamber.

With the exception of the diffusion chamber, the equipment and instruments were furnished by the Hydraulics Laboratory of the School of Civil Engineering. The diffusion chamber was fabricated by Mr. Homer J. Bates, instrument maker for the Hydraulics Laboratory.

ABSTRACT

Particle diffusion of six sizes of nylon particles was observed, recorded, and analyzed. The experimental apparatus was designed and the particles were selected to achieve the following:

(a) restriction of the particle motion to a horizontal plane thereby eliminating the effect of gravity;

(b) elimination of particle-to-particle collisions by observing the motion of widely separated individual particles;

(c) elimination of the effect of particle density by using nearly neutrally buoyant particles; and

(d) a homogeneous and isotropic field of fluid motion in which particle diffusion occurs without mean motion.

The motion of individual particles was recorded on motion-picture film, which was subsequently projected for displacement measurements.

The particle-displacement data were analyzed using the diffusion theory of continuous movement. The values of the particle diffusivity, ϵ_s, and particle mixing length, λ, as determined from an analysis of the data were plotted as a function of particle diameter, d. By extrapolation of these empirical functions to an infinitely small particle, values of fluid diffusivity, ϵ_o, and fluid mixing length, λ_o, were determined.

On the basis of this analysis, conclusions were drawn as follows:

(a) if $d < \lambda_o$, $\epsilon_s = \epsilon_o$;

(b) if $d > 3\lambda_o$, $\epsilon_s = o$; and

(c) ϵ_s/ϵ_o continuously decreases in the range $1 < d/\lambda < 3$.

Key words: diffusion, diffusivity, particles, turtulence.

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GLOSSARY

Symbol	Meaning	Dimensions
c	concentration	varies
d	diameter of spherical particle	L
f	film speed in frames per second	T^{-1}
i	subscript number for identification of motion-picture frames	—
L_t	Lagrangian time scale	T
N	oscillation parameter, $\sqrt{8\nu/a/d}$	—
n	time lag in frames	—
$P(\ )$	denotes "probability of"	—
p	total number frames	—
Q	rate of transport by diffusion	varies
$R(\tau)$	auto-correlation coefficient of velocity	—
t	time	T
$\sqrt{\overline{u^2}}, \sqrt{\overline{v^2}}$	root-mean-square velocities in the x and y directions, respectively	$L\,T^{-1}$
x,y,z	cartesian coordinates	L
Δx, Δy	particle displacements	L
$\overline{\Delta x^2}$, $\overline{\Delta y^2}$	mean-square displacements	L^2
β	ϵ_s/ϵ_m	—
ϵ	diffusivity	$L^2\,T^{-1}$
ϵ_h	diffusivity of heat	$L^2\,T^{-1}$

(Continued)

GLOSSARY (Continued)

Symbol	Meaning	Dimensions
ϵ_m	diffusivity of linear momentum	$L^2 T^{-1}$
ϵ_o	diffusivity of fluid	$L^2 T^{-1}$
ϵ_s	diffusivity of particles	$L^2 T^{-1}$
λ	mixing length of particles	L
λ_o	mixing length of fluid	L
ν	kinematic viscosity	$L^2 T^{-1}$
ρ	fluid density	$M L^{-3}$
ρ_s	particle density	$M L^{-3}$
τ	lag time	T
ω	angular velocity	T^{-1}

INTRODUCTION

Diffusion of marked fluid, heat, linear momentum, and foreign particles in a turbulent fluid are analyzed in a common mathematical framework, namely the Fickian diffusion equations,

$$Q = - \epsilon \cdot \text{grad } c \qquad (1)$$

and

$$\partial c/\partial t = \text{div } (\epsilon \cdot \text{grad } c) \qquad (2)$$

in which Q is the rate of diffusion, ϵ is eddy diffusivity, c is concentration, and t is time. Eddy viscosity is a vector having the dimensions of L^2T^{-1}. In equations 1 and 2, molecular diffusivity is neglected as being negligible in relation to eddy diffusivity.

In order to utilize equations 1 and 2 for the solution of an engineering problem with known initial and boundary conditions, the magnitude of the components of ϵ need to be known throughout the turbulent-flow field. Because of the complexity of turbulence, knowledge about eddy diffusivity is restricted to flow situations which have been experimentally studied. Examples of such flows are (1) radial diffusion in an axisymmetric jet issuing into an infinite reservoir [1, 2], (2) diffusion in a two-dimensional jet issuing into an infinite reservoir [1], (3) radial diffusion in fully developed flow in a circular pipe [1], (4) cross-channel diffusion on the surface of two-dimensional open-channel flow [4, 5], (5) lateral diffusion in fully developed two-dimensional flow between parallel walls and two-dimensional open-channel flow [6, 7],

and (6) diffusion of a rectangular jet issuing into an infinite reservoir 8 /.

Even though diffusion of any local characteristic of turbulent flow is analyzed by means of equations 1 and 2, the eddy diffusivity, ϵ, is dependent upon the local characteristic being diffused. In other words, the eddy diffusivities of marked fluid, ϵ_o, of heated fluid, ϵ_h, of linear momentum, ϵ_m, and of foreign particles, ϵ_s, are not identical in an otherwise identical flow. The ratio, ϵ_m/ϵ_h, is called the turbulent Prandtl number. The ratio, ϵ_m/ϵ_o, is called the turbulent Schmidt number. The turbulent Prandtl and Schmidt numbers are approximately 0.7 for gases 9 /. The corresponding ratio for foreign particles, ϵ_m/ϵ_s, is unnamed but the inverse of this ratio is commonly used in the literature of solid-particle diffusion, that is,

$$\beta = \epsilon_s/\epsilon_m \qquad (3)$$

Vanoni 10 / has presented an excellent treatise on the suspension of sediment in which β is extensively discussed.

A mathematical expression for the ratio, ϵ_s/ϵ_o, was presented by Carstens 11 /. Carstens experimentally determined values of virtual-mass coefficients and equivalent viscous damping coefficients for a spherical particle oscillating with simple harmonic motion in a still fluid. He then utilized the experimentally determined values of these coefficients in the equation of motion of a sphere in an oscillating fluid in order to solve for the ratio of spherical-particle

amplitude to the fluid amplitude. The solution for the amplitude ratio using the experimentally determined coefficients was found to be nearly identical to that obtained using the analytically determined coefficients derived by Stokes [12] for the case of laminar fluid motion around the oscillating sphere. This finding was incorporated into a subsequent analysis for the diffusivity ratio, ϵ_s/ϵ_o, yielding the following expression

$$\frac{\epsilon_s}{\epsilon_o} = \frac{(1 + 3N/2)^2 + \left[(3\,N/2)(1 + N)\right]^2}{\left[(2/3)(\rho_s/\rho) + 1/3 + (3\,N/2)\right]^2 + \left[(3\,N/2)(1 + N)\right]^2} \qquad (4)$$

in which ρ_s is the sphere density, ρ is the fluid density, and N is the oscillation parameter, $\sqrt{8\,\nu/\omega}/d$, in which ν is the kinematic viscosity, ω is the circular frequency, and d is the particle diameter. For a density ratio, ρ_s/ρ, of unity, the diffusivity ratio is unity irrespective of the value of the oscillation parameter. Carstens' analysis is questionable in three respects as follows: (1) gravitional forces were not considered, (2) linear oscillation was substituted for the vastly more complex fluid motion associated with turbulence, and (3) the particle was completely surrounded by the linearly oscillating fluid thereby restricting the analysis to particles which are much smaller than the turbulent eddies.

Rouse [13] performed a basic study in particle diffusion by measuring the concentration in the vertical direction of sand particles in which the turbulence was in repeating patterns in the vertical direction. The apparatus consisted of a cylindrical glass

jar filled with water in which a lattice-structure agitator was oscillated vertically with simple harmonic motion. The amplitude was constant in all runs. The frequency of the agitator was varied from 0.8 to 5 cycles per second. Four different quartz sands were used--1/4 mm, 1/8 mm, 1/16 mm, and 1/32 mm. After the steady-state condition had been reached, samples were withdrawn at 16 levels in the jar. The concentration of sand in each sample comprised the data for calculating the concentration gradient in the vertical. In the steady state, the rate of sediment transport upward by diffusion is exactly equal to the rate of transport downward by settling. Using the experimentally determined values of settling velocity, concentration, and concentration gradient, values of particle diffusivity, ϵ_s, were calculated from the solution of equation 1. For frequencies less than 3 cycles per seconds, the values of ϵ_s were identical for all four sands and were proportional to the agitator frequency. For frequencies greater than 3 cycles per second the values of ϵ_s of the 1/4 mm and 1/8 mm sands increased faster than the increase in frequency. This result is exactly opposite to the relationship in equation 4. The oscillation parameter, N, is inversely proportional to particle diameter, d. According to equation 4, the value of ϵ_s should have been less for the larger sands at the same frequency. The surprising result of this carefully performed experiment could have been the consequence of more frequent direct impacts of the larger sands with the agitator, whereas the analysis is predicted upon momentum transfer solely from fluid to solid particle. A second possibility is that the settling velocity within

the turbulent fluid is not the same as the settling velocity within a quiescent fluid. Of course, the third possibility is that ϵ_s does increase with larger particles.

Ho [14] found that the fall velocity in an oscillating fluid was significantly lower than in a still fluid. Spheres were released in an 18-inch long, 3.5-inch inside diameter cylinder, which was oscillated vertically. Particle-displacement data were recorded photographically. The experiments covered a wide range of variables by using spheres of different sizes and densities, mixtures of glycerine and water, different oscillation frequencies, and different amplitudes of oscillation. Reasonable values of the settling velocity in an oscillating fluid were found to be predictable from numerical solutions of the equation of motion. Ho [14] also analyzed Rouse's results [13] and found that the apparent increase in ϵ_s with the two largest sizes of sand could be explained as a consequence of the reduced settling velocity.

Brush [15] made a study of the diffusion of glass beads in a submerged axisymmetric jet in order to compare the characteristics of the diffusion of sediment with those of momentum in free-turbulence shear flow. A vertical 1/4-inch jet of sediment-laden water was directed downward into a 14-inch-diameter cylindrical tank of still water. Small concentrations of nearly spherical glass beads were introduced into the recirculating system. The efflux velocity was maintained at 20 ft/sec or more to lessen the relative importance of the fall velocity of the individual particles. Concentration profiles of the sediment were measured at various downstream sections in the

zone established flow and were compared with the velocity profiles at the same sections. The diffusion characteristics of the sediment-laden water were analyzed by use of the approximate theories derived for clear-water jets. The values of β, equation 3, as determined above, are listed in TABLE I.

TABLE I

BRUSH'S DIFFUSIVITY RESULTS

Particle mean diameter (mm)	ϵ_s/ϵ_m
0.55	0.15
0.32	0.50
0.19	1.00

In assessing the results, the question of changes in fall velocity with turbulence characteristics is partially avoided by this ingenious experiment in which particle concentrations were measured in horizontal planes and in which the jet velocities were much larger than the fall velocity. In spite of this rational way of avoiding a fall-velocity effect, a duplication of some of the runs with the jet directed vertically upward would have been very interesting.

Singamsetti [16] repeated the earlier experiments of Brush [15] because of the possibility of recirculation of sediment within the 14-in-diameter cylindrical tank used in the earlier experiments. The tank into which the submerged jet was directed was 72 inches in

diameter. The nozzle diameter was 0.262 inches. The initial jet velocity was 20 ft/sec in all tests with the five different sands having a geometric mean sieve diameter of 0.068 mm, 0.115 mm, 0.23 mm, 0.32 mm, and 0.46 mm. Velocity and concentration traverses were made in planes perpendicular to the jet axis in four horizontal planes located at 18, 24, 30, and 36 nozzle diameters from the nozzle. The results were indeed different from the earlier experiments as shown in TABLE II.

TABLE II

SINGAMSETTI'S DIFFUSIVITY RESULTS

Particle diameter (mm)	Particle Reynolds number*	ϵ_s/ϵ_m
0.068	0.4	1.23
0.115	1.2	1.20
0.23	7.2	1.24
0.32	18	1.39 and 1.35
0.46	33	1.45 and 1.43

*Velocity is the fall velocity in the quiescent infinite fluid at the same temperature

From the results of this study, Singamsetti concluded that (a) the linear-oscillation model is invalid for three-dimensional turbulence, (2) the value of ϵ_s/ϵ_o is unity ($\beta = 1.2$) within the Stokes range, and (3) the value of ϵ_s/ϵ_o is greater than unity with

particle Reynolds numbers beyond the Stokes range provided that the fall velocity is less than the rms value of the turbulence fluctuations in the direction of fall. The explanation offered is that the larger particles ($\rho_s/\rho > 1$) are thrown outward and into another eddy by virtue of the circulatory motion of the turbulent eddies. If so, the coarse-sand particles would experience more transfers from one eddy to another than fine-sand particles per unit time in a given turbulent field. In other words, with the circulatory-flow model the difference in solid particle trajectory and fluid-particle trajectory is indicative of values of ϵ_s/ϵ_o greater than unity if $\rho_s/\rho > 1$; whereas the opposite is indicated with the linear-oscillation model.

Farmer 17/ performed a study in which ϵ_o and ϵ_s were determined by means of a parallel set of experiments in a diffusion chamber. The diffusion chamber was a rectangular prism being 6-in wide, 22.4-in long, and 1-in deep. One of the 6-in by 22.4-in walls was studded with 0.190-in diameter jets. By means of an oscillating piston, each jet was made to discharge and to exhaust water from the chamber during a cycle. The seventy-two nozzles were placed so as to obtain repeating patterns of eddies along the 22.4-in. dimension of the chamber. Frequency and amplitude of the piston pump were the controlled variables. Values of ϵ_o were calculated from the solution of equation 2 for the case of instantaneous injection of dye at one cross section of the diffusion chamber. Dye concentration at a distance from the injection plane was measured as a function of time by

measuring light transmissibility. Values of ϵ_s were determined from the steady-state concentration gradient of 0.297-mm spherical particles having a density ratio, ρ_s/ρ, of 1.31. The particles were ion-exchange resin beads, which were tagged with radioactive cesium. Counts of gamma emissions were assumed to be proportional to particle concentration. In order to diminish but not eliminate the effect of the gravity force, the diffusion chamber was inclined 77 degrees from the vertical. In utilizing the solution of equation 2 the particle settling velocity along the axis of the chamber is required in order to compute ϵ_s. Farmer did not determine the settling velocity, but computed the settling velocity accounting for the tilt of the column and assuming that the boundary layers around the particles were turbulent. Values of ϵ_o, ϵ_s and ϵ_s/ϵ_o, as determined by Farmer, are listed in TABLE III. The values of ϵ_s/ϵ_o, as calculated by Farmer from experimental measurements, are all less than unity. The principal weakness in Farmer's study is that he was able to determine the ratio of the settling velocity to particle diffusivity from experimental measurements and the solution of equation 1 with the result that in order to calculate ϵ_s he utilized a derived settling velocity of doubtful merit. Farmer's experiments are analogous to Rouse's [13] in that an artificial field of turbulence was created which was homogeneous and isotropic in an incremental sense. Rouse's equipment was inferior to Farmer's in that particle impact with a moving mechanical agitator was possible in Rouse's experiments. Farmer's experiment would be of far greater value had he placed his

TABLE III

FARMER'S DIFFUSIVITY RESULTS

Pump		Diffusivities		$\frac{\epsilon_s}{\epsilon_o}$
Frequency (cps)	Amplitude (in.)	Particle (ft^2/sec)	Fluid (ft^2/sec)	
2	2.0	0.00094	0.00132	0.71
	2.5	0.00125	0.00172	0.73
	3.5	0.00189	0.00222	0.85
3	1.5	0.00113	0.00189	0.60
	2.0	0.00152	0.00219	0.69
	2.5	0.00164	0.00281	0.58
	3.5	0.00372	0.00467	0.80
4	1.5	0.00144	0.00287	0.50
	2.0	0.00199	0.00323	0.62
	2.5	0.00337	0.00395	0.85
	3.5	0.00368	0.00584	0.63
5	2.0	0.00292	0.00418	0.70
	2.5	0.00457	0.00555	0.82

diffusion chamber in the horizontal to eliminate the gravity force (settling velocity) and used the solution of the unsteady state diffusion equation, equation 2, to solve for ϵ_s in exactly the same way that he determined ϵ_o.

Attempts to determine the value of β by measurement of sediment concentration (in the vertical) in flumes and streams and to utilize the solution of equation 1 to calculate β have been quite inconclusive not only because of the unknown effect of the turbulent motion on settling velocity, but also because the particles undoubtedly affect the turbulence field and mean-velocity distribution. In his careful review of this subject, Vanoni [10] notes that values of β have been reported to vary in laboratory experiments (flume experiments) from 1.0 to 1.5.

From this brief review of some significant experiments regarding the ratio of solid-particle diffusivity to fluid diffusivity, ϵ_s/ϵ_o, or to diffusivity of linear momentum, β, one conclusion is predominant, namely, that a basic study of solid-particle diffusion in a turbulent fluid is very difficult because the systematic variation of one independent variable is nearly impossible without inducing an unwanted change in one or more of the other independent variables. Examples of these unwanted changes are as follows: (a) except for very low concentrations, solid particles can be expected to alter the turbulence; (b) the settling velocity in a turbulent field is known to be a function of concentration and appears to be a function of the turbulence; (c) except for very low concentrations particle-to-particle impact is a factor in particle diffusion; and (d) turbulence can not be generated by mechanical agitators because of the particle-to-agitator impact is a factor which enhances particle diffusion quite distinct from that by turbulent eddies.

The specific object of the experimental study reported herein is to study the effect in particle diffusion of solid-particle diameter in relationship to a length scale of the turbulent field. The basic equipment is that used by Farmer [17]. The effect of gravity force and/or settling velocity is eliminated by placing the diffusion chamber so that particle diffusion occurs only in a horizontal plane. The repeating arrangement of jets is to insure homogeneity and isotropy of the turbulence--at least in a gross sense over a repeating pattern. Inertial effects are minimized by use of particles for which the density ratio, ρ_s/ρ, is nearly unity. Diffusion is determined from particle displacements as determined from successive frames of a motion picture.

The proposed plan and the plan which was initially followed was to utilize the same diffusion chamber which had been used previously by Farmer and to release a group of particles at $t = 0$. Particle diffusivity, ϵ_s, was to be calculated from the solution of equation 2 and from particle-position distributions as recorded on the motion-picture film. Fluid diffusivity, ϵ_o, had been determined by Farmer in this chamber by dye diffusion. Experimental results indicated that the planned method of attack was unsatisfactory for two reasons. First, the eddy diffusivity is nearly zero adjacent to the sidewalls where the jet flow is physically restrained by the sidewall. With the passage of time most of the particles become trapped in this wall region where these particles merely oscillate without diffusion. This effect was not observed in Farmer's

experiments because the particles which did become trapped within the wall region would migrate toward the bottom of the chamber by virtue of the gravity force. Second extremely low concentrations of particles were found to be necessary in order to preclude a significant number of particle-to-particle impacts. With low concentration and with wall entrapment, the particle population became too small for a reasonably accurate statistical analysis of the particle-group dispersion.

After these unpleasant discoveries, the diffusion chamber was redesigned to be circular in plan so as to minimize the length of sidewall and to provide a large central region which is completely free from the turbulence discontinuity adjacent to sidewalls. In order to avoid the effect of particle-to-particle impacts, particle diffusivity was determined by statistical analysis of trajectories of individual particles. The following report is confined to experiments conducted in the circular diffusion chamber and to the analysis of particle trajectory.

II. THEORY

All of the experimental studies reported in the INTRODUCTION utilized the solution of one of the Fickian diffusion equations, equation 1 or equation 2, in order to calculate particle diffusivity. A more basic approach is to determine the particle diffusivity from experimental measurements of particle displacement, Δx, Δy, and Δz, during equal-time increments, Δt. The theoretical basis for determining diffusivity by measurement of displacement of an individual particle is given in the following.

A. Diffusion by discontinuous movements

By assuming that particle displacements, Δx, are normally distributed and that each displacement, Δx, which occurs during the time Δt is independent of the displacement which occurred in the previous time increment, Einstein 18/ proved that the probability, $P(x,t)$, of a particle being located at the position x at the time t is

$$P(x,t) = \frac{1}{2\sqrt{\pi \epsilon_x t}} e^{-x^2/4\epsilon_x t} \qquad (5)$$

in which

$$\epsilon_x = \frac{1}{2} \frac{\overline{\Delta x^2}}{\Delta t} \qquad (6)$$

Equation 5 is a normal distribution which was derived for the probability of an individual particle being located at x. If a large number of non-interfering particles were released at $x = 0$ when

t = 0, the spatial distribution of the cloud would be identical to the probability distribution of a single particle. In other words, the solution of the one-dimensional diffusion equation, equation 2, is identical to the probability distribution of a single particle being released at x = 0 when t = 0. The important point is that the particle diffusivity ϵ_x can be determined from measured displacements of an individual particle by means of equation 6.

If particle diffusion occurs in two dimensions, equation 5 is the probability distribution in either of the two perpendicular directions provided that the Δx's and the Δy's are normally distributed. The diffusion process is said to be isotropic if $\epsilon_x = \epsilon_y$ and non-isotropic or anisotropic if $\epsilon_x \neq \epsilon_y$.

The assumption of the normal distribution of the displacements, Δx and Δy, requires that the diffusion process be homogeneous and statistically steady, that is, ϵ_x = constant and ϵ_y = constant.

The preceding derivation assumed a non-flow situation with a fixed origin of coordinates. Of course, if the entire field of diffusion were being translated at a constant velocity, equation 5, would be the probability distribution with reference to a moving coordinate system. If the field of diffusion is being translated with a velocity which varies in one of the coordinate directions, equation 5, is no longer applicable. In fact, the spreading of a cloud of particles by dispersion resulting from non-uniform velocity distribution can be far greater than that from diffusion alone.

In the derivation of equation 5, Einstein assumed that the displacements, Δx, in the constant time increment Δt were independent.

In other words, the time Δt is small compared to the total observation time but large enough so that the movements executed by a particle in two successive time increments are independent.

The theory outlined above has become known as discontinuous diffusion 19/ because the normal distribution of the displacements result from considering the particle motion to occur in equal-length motions and with identical speeds, but with no correlation in regard to direction of the paths.

B. Diffusion by continuous movements

In the classic theory of Taylor (as related by Goldstein 19/), particle motion is considered to be continuous in a statistically steady, isotropic field of turbulence with a zero mean velocity. The mean-square displacement of a cloud of particles from a plane yz where all the particles are concentrated at time t=0 was found to be

$$\overline{\Delta x^2} = 2\,\overline{u^2} \int_0^t (t-\tau)\, R(\tau)\, d\tau \qquad (7)$$

in which $\overline{\Delta x^2}$ is the variance of the group of particles at time t; $\overline{u^2}$ is the mean square velocity in the x direction; τ is a time lag; and $R(\tau)$ is the auto-correlation coefficient of velocity. The auto-correlation coefficient is defined as follows

$$R(\tau) = \frac{\overline{u(t)\, u(t+\tau)}}{\overline{u^2}} \qquad (8)$$

in which the bars denote mean values. Equation 7 was derived by

Kampé de Fériet from the double integral term derived by Taylor (as related by Sayre and Chamberlain 5/).

When the time is very large, equation 7 reduces to

$$\overline{\Delta x^2} = \overline{2u^2}\, L_t t - 2\,\overline{u^2} \int_0^\infty \tau\, R(\tau)\, d\tau \qquad (9)$$

in which L_t, the lagrangian time scale, is

$$L_t = \int_0^\infty R(\tau)\, d\tau \qquad (10)$$

When the time is large, the last term of equation 9 is negligible. In this case

$$\overline{\Delta x^2} \sim 2\overline{u^2}\, L_t\, t \qquad (11)$$

The diffusion coefficient ε_x is $\overline{u^2}\, L_t$. The diffusivity is seen to be equal to one-half the slope of curve of mean-square displacement versus time at large times - that is, differentiating equation 11

$$\varepsilon_x = \overline{u^2}\, L_t = \frac{1}{2} \frac{d\,(\overline{\Delta x^2})}{dt} \qquad (12)$$

A reasonable empirical relationship for $R(\tau)$, which is compatible with equation 10, is an exponential function 5/ as follows

$$R(\tau) = e^{-\tau/L_t} \qquad (13)$$

Substituting equation 13 into equation 7, Frenkiel (as reported by Sayre and Chamberlain [5]) found the following approximations to the solution

$$\frac{\overline{\Delta x^2}}{\overline{u^2}\, L_t^2} = \left(\frac{t}{L_t}\right)^2 \qquad 0 < \frac{t}{L_t} < 0.03 \qquad (14a)$$

$$\frac{\overline{\Delta x^2}}{\overline{u^2}\, L_t^2} = 2\, e^{-t/L_t} + \frac{t}{L_t} - 1 \qquad 0.03 < \frac{t}{L_t} < 3.63 \qquad (14b)$$

and

$$\frac{\overline{\Delta x^2}}{\overline{u^2}\, L_t^2} = 2\left(\frac{t}{L_t} - 1\right) \qquad 3.63 < \frac{t}{L_t} \qquad (14c)$$

Equation 14c is seen to be identical to equation 11, except for the intercept value, $-2\,\overline{u^2}\, L_t^2$.

Goldstein [19] defines a mixing length (diffusion length) as

$$\lambda = L_t \sqrt{\overline{u^2}} \qquad (15)$$

If the particles are moving identically with the surrounding fluid, then the mixing length as given by equation 15 is also a length scale of the turbulence, λ_o.

III. EQUIPMENT AND INSTRUMENTATION

The equipment was designed to create a field of turbulence in which solid-particle trajectories could be observed and could be recorded on motion pictures. The apparatus was designed so that the assumptions used in the derivation of equation 5 and 6 would be fulfilled in the diffusion chamber. These assumptions were (1) that the turbulence be homogeneous, (2) that there be no mean flow through the diffusion chamber, and (3) that the only driving force on a solid particle be the hydrodynamic force of fluid acting on a particle, in other words, the force of gravity is eliminated. In addition the diffusion chamber was designed to produce isotropic turbulence.

The apparatus is located in a small room in the Hydraulics Laboratory of the Georgia Institute of Technology. This room is insulated and air conditioned.

A. Equipment

1. Diffusion chamber

The diffusion chamber is circular in plan with inside diameter of 13.20 inches and with a depth of 1.00 inch as shown in figures 1 and 2. The bottom is 1/2-inch plate glass in order that particle motion can be observed from below. The sidewall is a ring of transparent plastic in order that the chamber can be illuminated by means of 24, 6-volt, incandescent light bulbs spaced around the periphery of the sidewall. The top is a 3/8-inch-thick brass plate studded with 68, 0.190-inch-diameter holes. The circular holes are nozzles through which distilled water is alternately discharged into

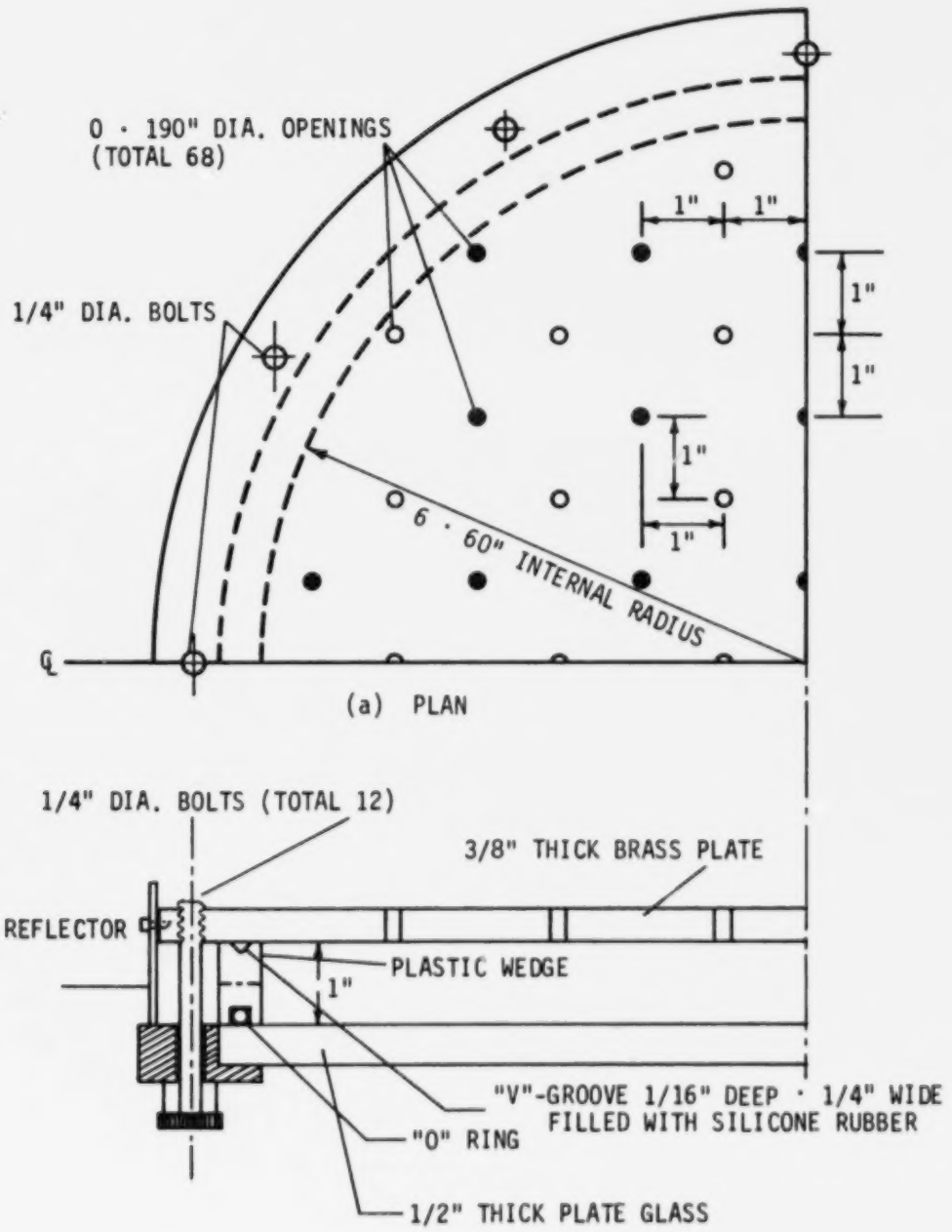


Figure 1. Cross Sections of the Diffusion Chamber.

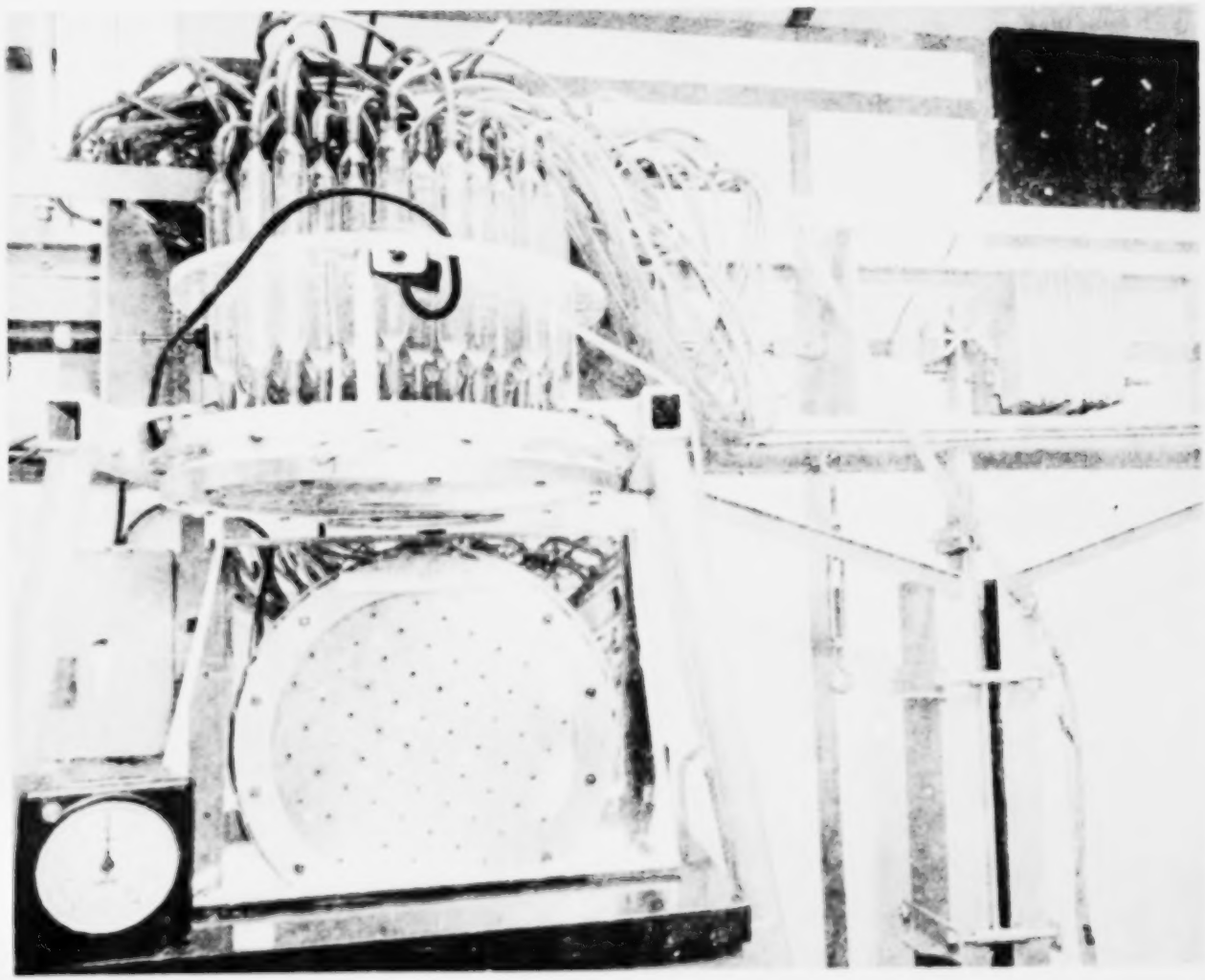


Figure 3. Diffusion Chamber.

and exhausted from the chamber. The geometric arrangement of the nozzles as shown in figure 1 is to attain homogenity of the flow field within the chamber--at least in a gross sense over a repeating pattern of nozzles. Each nozzle is connected to a piston pump so that each nozzle discharges onto the chamber during one-half cycle and exhausts from the chamber during the other half cycle. In order to maintain a mass balance in the fixed volume, one half of the nozzles are discharging into the chamber while the other half are exhausting.

2. Pump and manifolds

The pump which forces water in and out of the nozzles is a 2-inch-diameter, double-acting piston centered in a brass cylinder as shown in figure 3. Each end of the pump cylinder is connected to a circular copper manifold shown in figure 3. The conical tops surmounted by bleeder valves are used to remove air from the system. Connecting tubes are spaced uniformly around the periphery of the 8-inch diameter manifolds. Each 1/4-inch diameter nipple on the manifolds is connected to a nozzle on the diffusion chamber by means of a length of plastic tubing and sediment trap located directly above the nozzle. The glass sediment traps are visible in figure 2. Of course, the function of the sediment traps is to preclude migration of a solid particle back to the pump. The symmetry of the manifolds and the equality of each connecting line is to insure that the flows in each nozzle are equal.

In order to preclude cavitation in the pump and to insure that the system was completely filled with water at all times, the water

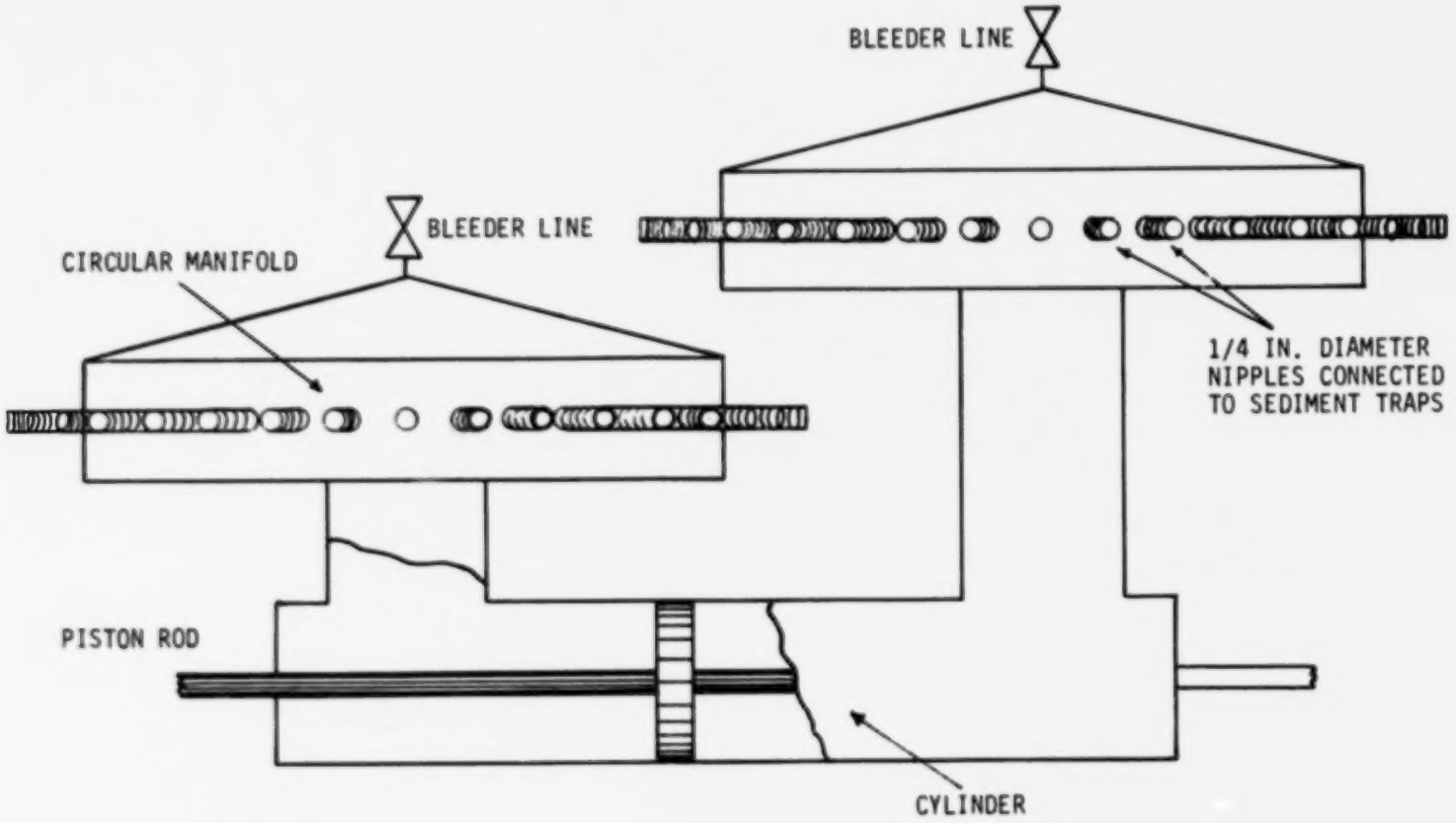


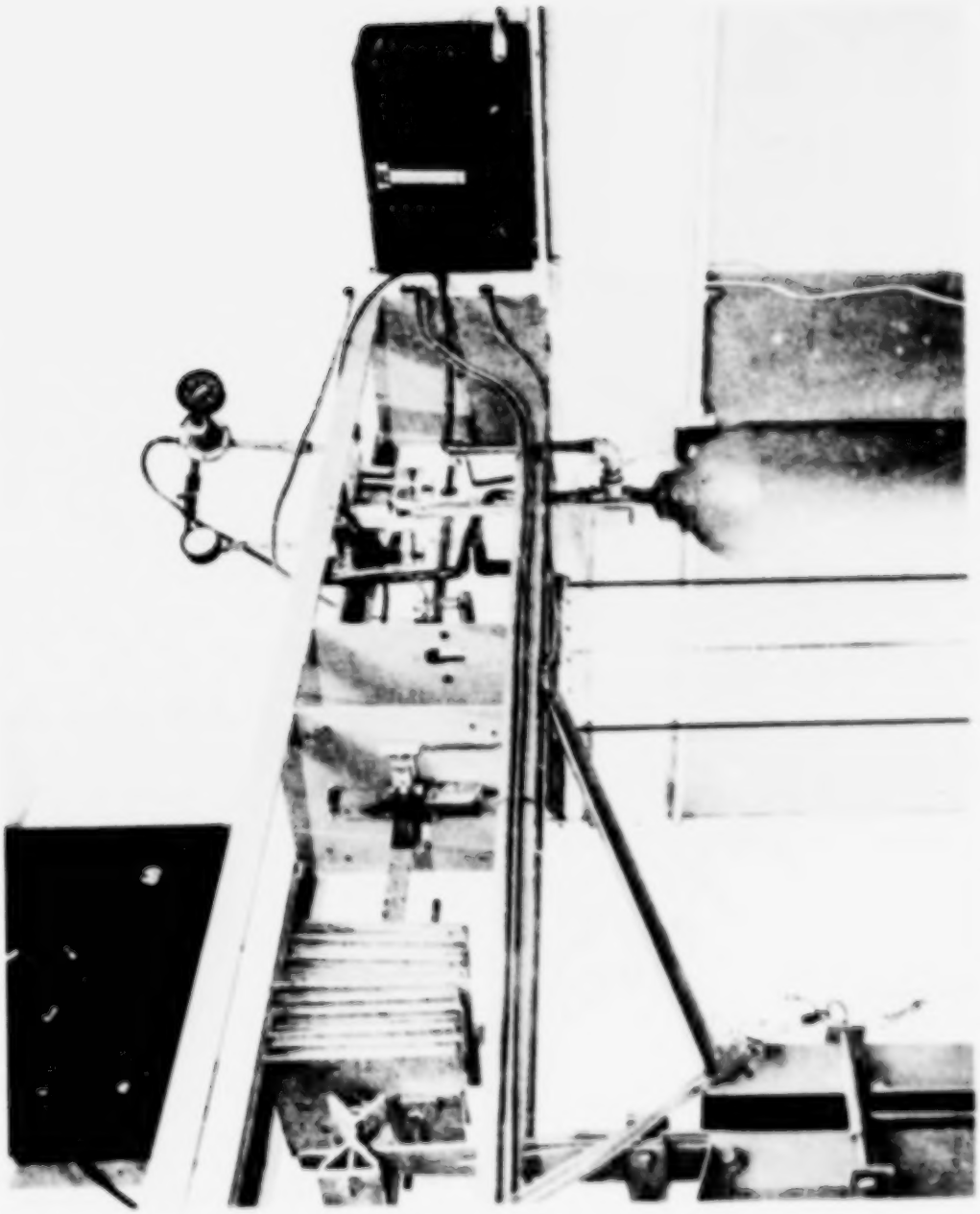
Figure 3. Pump

system was pressurized by connection to a pressurized distilled-water reservoir.

3. Pump drive

The force required to oscillate the piston of the pump is supplied by two-double-acting air pistons located at the extremities of pump shaft. The frequency of the oscillation is established by means of a solenoid valve which reverses the direction of the flow of air in the supply lines to the air pistons. The frequency of switching of the solenoid valve is controlled by an electronic timing unit. The amplitude of oscillation is controlled by regulation of the air pressure being supplied to the air pistons.

The undesirable pump-piston motion resulting from the square-wave driving force was eliminated by attaching a spring-mass system to the pump-piston rod. As shown in figure 4, a portion of the pump-piston rod is a 1-inch-square steel bar upon which 1/4-inch steel plates are clamped. The oscillating mass can be varied by the number of steel plates which are clamped to the piston rod. The spring, shown in the photograph, is a leaf spring one end of which is clamped in a floor-mounted base. The other end of the spring is forced to move with the piston rod by being confined between the halves of a rocker bearing. Experimentally determined amplitude-frequency curves are shown in figure 5 with 18 steel plates clamped to the piston rod. Each curve in figure 5 was obtained with a different regulated air pressure to the driving pistons. The resonant frequency with 18 plates is seen to be about 2.85 cycles per second. The motion curves were found to be nearly simple harmonic with oscillation frequencies



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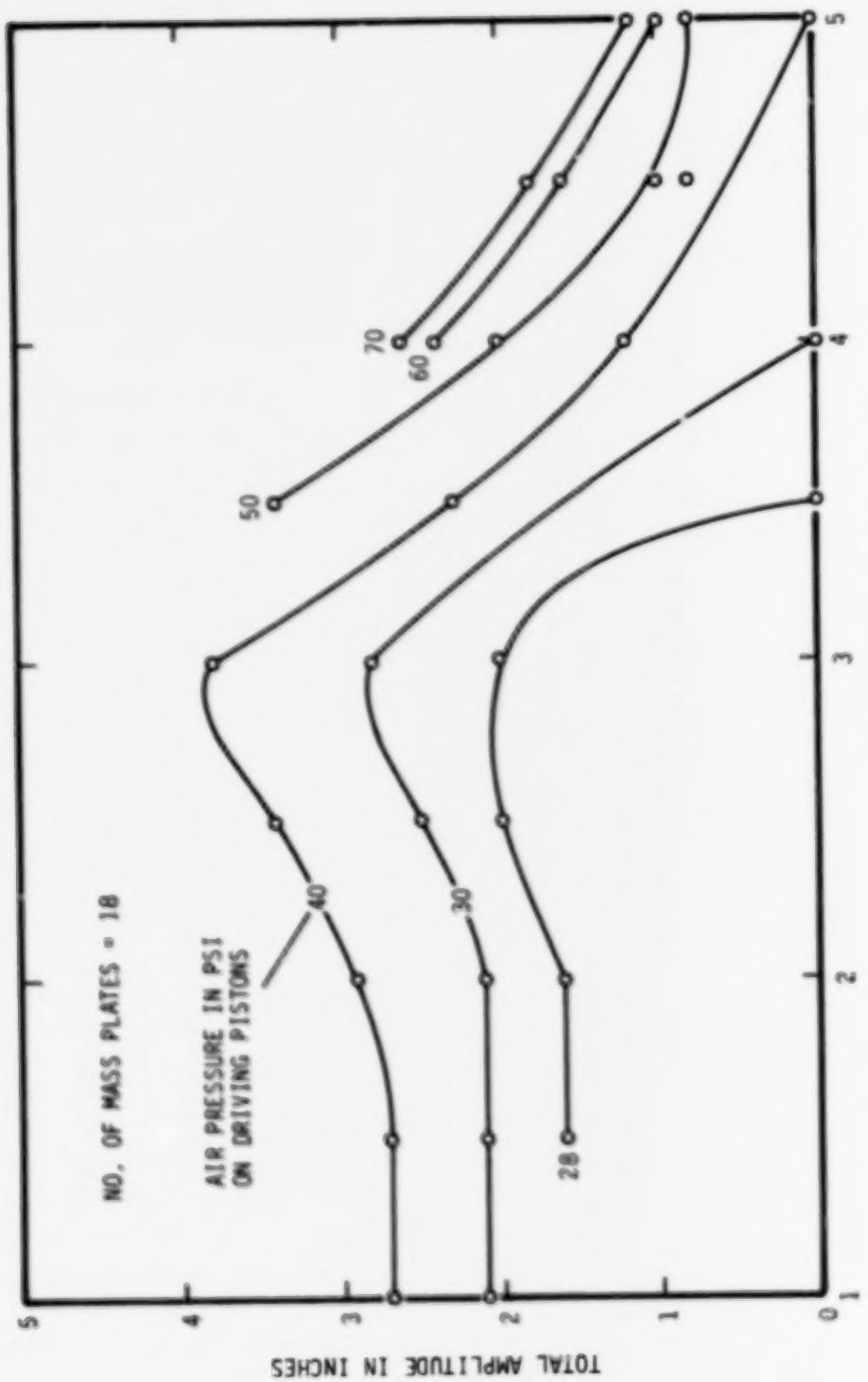


Figure 5. Amplitude-frequency Curves.

greater than the resonant frequency.

B. Instruments

The motion curve of the piston rod and a timing mark were simultaneously recorded on a direct-writing oscillograph. The piston-rod position was detected by means of a differential transformer mounted so that the core could be attached to the piston rod. The differential transformer was connected with a commercially available transducer-amplifier-indicator unit (Sanborn Model 311A). The dc output of the transducer-amplifier-indicator unit was again amplified in order to drive a direct-writing oscillograph. The motion-curve recording system was calibrated just before and just after each run by positioning the piston rod at various displacements and by making a short record on the recorder chart at each of the known positions. A screw jack was used to displace the piston rod in order to oppose the restoring force of the spring. A motion-curve record was obtained continuously during each run. The amplitude and frequency of oscillation could be determined from the motion-curve record.

Particle positions were recorded on motion pictures. The motion-picture camera operated at a rate of 16 frames per second. The plate-glass mirror shown in figure 2 was used to redirect the light from the interior of the diffusion chamber from vertically downward to horizontal. After the film was developed, the images were projected onto sheets of drawing paper where the position of a particle was marked frame by frame.

C. Particles

The particles were precision seamless nylon spheres manufactured

by the Ace Plastic Company of Jamaica, New York. Pertinent properties of the particles are given in TABLE IV.

TABLE IV

PROPERTIES OF SPHERICAL NYLON PARTICLES

Diameter		
Nominal (in)	Actual (in)	Specific gravity
1/2	0.500 ± 0.001	1.14
3/8	0.375 ± 0.001	1.14
9/32	0.281 ± 0.001	1.14
7/32	0.219 ± 0.001	1.14
5/32	0.156 ± 0.001	1.14
3/32	0.094 ± 0.001	1.14

IV. SCOPE AND PROCEDURE

A. Scope

Two runs were made under identical conditions of pump frequency and amplitude. In each of these runs three different particle sizes were placed in the diffusion chamber. The diameter and quantities are shown in TABLE V. Particle concentration was small enough to preclude particle-to-particle collisions.

TABLE V

SCOPE OF EXPERIMENTS

Run	Water Temp. ($^{o}_{F}$)	Amplitude (in)	Frequency (cycles per sec)	Particles	
				Diameter (in)	No. in Chamber
15	63.5	2.10	3.60	1/2	5
				9/32	9
				5/32	10
16	64.5	2.10	3.60	3/8	7
				7/32	10
				3/32	20

B. Procedure

1. Making a run

The following is a chronological description of the procedure for making a run.

The room air-conditioner is turned on at least 24 hours ahead of making a run and set at the required temperature.

The spherical particles are introduced into the diffusion chamber. The cylindrical water reservoir is pressurized to about 3 psi and distilled water is forced into the diffusion chamber through two ports.

The bleeder valves at the top of the manifolds, figure 3, are kept open to remove all the air from the system. Water rises through the diffusion chamber, through the jet openings into the sediment traps, through the connecting tubes into the manifold, and finally through the bleeder valves. Generally some air still remains entrapped in the connecting tubes. The trapped air is taken out by manipulating the flexible tubes. The bleeder valves are closed when all the air is removed from the system.

The piston-rod-motion-recording system is calibrated by moving the spring-mass system, figure 4, to the left and to the right of the mean position in increments of $\frac{1}{2}$-inch.

The pressure in the diffusion chamber is increased to 5 psi.

The electronic timer is switched to produce an oscillation frequency of 3.60 cycles per second.

The pump is started by slowly increasing the pressure in the air pistons. After the pump is oscillating, the desired amplitude can be attained by slight adjustment of the pressure regulator shown in figure 4.

The piston-rod-motion recording system is turned on.

Water temperature is recorded.

The clock is started.

Meanwhile, the 16-mm motion-picture camera is positioned and focused. The diffusion chamber is illuminated.

The camera is started and about 5 minutes of particles motion is recorded.

The pump is stopped by decreasing the pressure in the air pistons.

The motion-recording system is turned off.

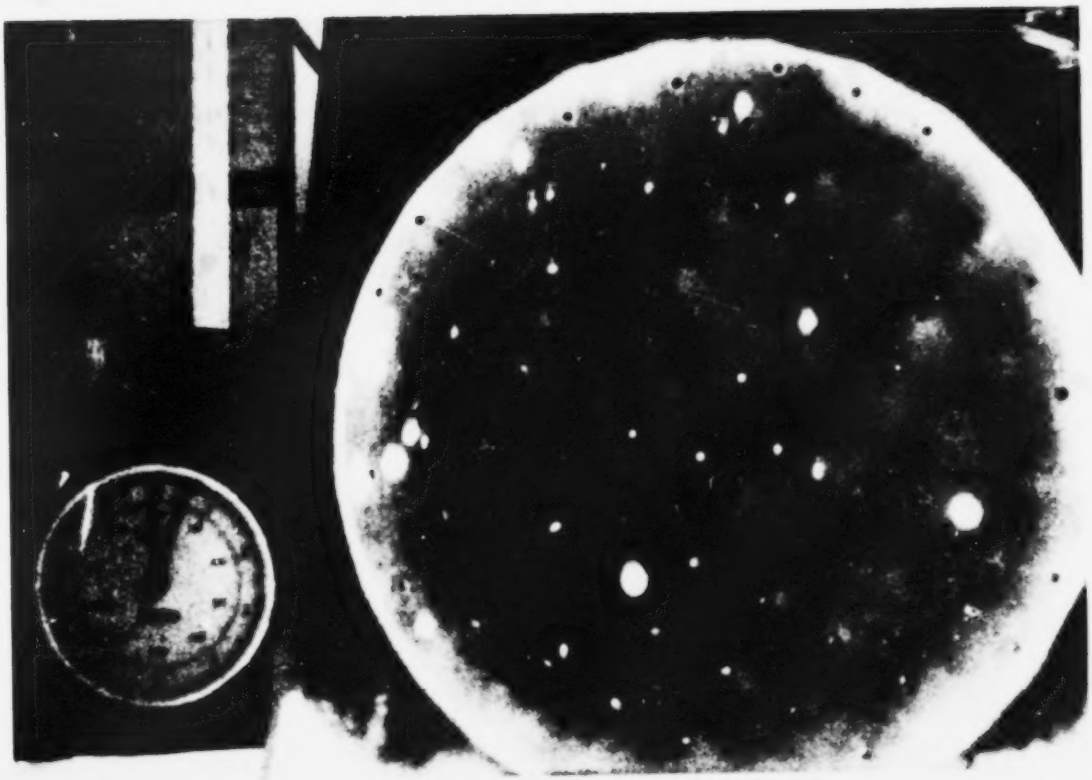
Final water temperature is recorded.

The piston-rod-motion recording system is again calibrated.

2. Data reduction

The developed film is projected frame by frame on to a large sheet of paper attached to the vertical wall. Figure 6 is frame no. 20 of Run 16. A circular template is used to draw the outline of each particle on the sheet. The center of the diffusion chamber is taken as the origin. The position of each particle is measured from an orthogonal set of axes. The same axes were used throughout.

Coordinates of a particle are obtained by drawing a pair of tangents to the particle parallel to the axes. Coordinates of the particle are fixed by measuring the perpendicular distances from the tangents to the axes. When the particle is displaced to a new position in subsequent frames, tangents are drawn as before on the same sides of the particle. The new coordinates are assigned as before. Particle displacements between frames are easily obtained as the difference between the x and the y coordinates. There is no need to locate the center of the particle. Time is obtained with reference to the frame number. Any arbitrary frame number can be



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assigned to the first frame, so that the time interval between any two particle positions is given by the difference in their frame numbers. Time can also be checked by the clock. Particle coordinates were punched on cards.

3. Computations

With the particle coordinates recorded in digital form on punched cards all numerical computations could be readily performed using the Burroughs B-5500 electronic digital computer in the Rich Electronic Computer Center of Georgia Institute of Technology.

V. RESULTS

A. Experimental results

Particle coordinates are presented in TABLES A I - A VI, inclusive, in APPENDIX A. Each table contains data for one size of particle. A discontinuity or duplication of the frame number indicates a change from one particle to another.

B. Computed results

1. Auto-correlation

Since the particle trajectories were recorded on motion pictures by means of a camera that exposes f frames per second, the time lag τ in the correlation coefficient (equation 8) can be conveniently expressed as $\tau = n/f$ in which n is time lag in motion-picture frames and in which $1/f$ is the time interval between each frame. If each frame is numbered with the integer subscript i, the x component of velocity is approximated as follows

$$u\left(\frac{i - 0.5}{f}\right) \sim (x_i - x_{i-1})\, f \qquad (16a)$$

and at n frames later

$$u\left(\frac{i + n - 0.5}{f}\right) \sim (x_{i+n} - x_{i+n-1})\, f \qquad (16b)$$

Substituting equations 16a and 16b into equation 8

$$R(\tau) = \frac{\overline{(x_i - x_{i-1})(x_{i+n} - x_{i+n-1})}}{\overline{(x_i - x_{i-1})^2}} \qquad (17)$$

Values of $R(\tau)$ were computed for all six particles and in both coordinate directions. The computed results for the 3/32-inch-diameter particle are shown in figure 7. The continuous function shown in figure 7 is computed from equation 13 with the numerical values, f = 16 frames per second and L_t = 1.2/f or 0.075 sec.

2. Displacements

Displacements and the variance of displacements were calculated for all six particles with time lag in frames of n = 1, 2, 3, 4, 6, 8, and 10. Of course, displacement is

$$\Delta x_{i+n} = x_{i+n} - x_i \tag{18a}$$

and

$$\Delta y_{i+n} = y_{i+n} - y_i \tag{18b}$$

The frequency distribution of the Δx's and the Δy's for the 3/32-in-diameter particle with n = 3 is shown in figure 8. The normal distributions having the same standard deviation as the variance of the experimentally determined displacements are also shown in figure 8. Since the chamber was designed for zero mean flow, the mean displacement, $\overline{\Delta x}$, was expected to be zero. The non-zero value of $\overline{\Delta x}$ shown in figure 8(a) is indicative of drift in the negative x direction. The corresponding drift velocity is 0.045 feet per second. The slight drift in the x direction of the 3/32-in particles was not observed with either of the other two sizes of particles during the same run, Run 16. Consequently, drift was ignored in calculating the mean-square displacements (variance), that is

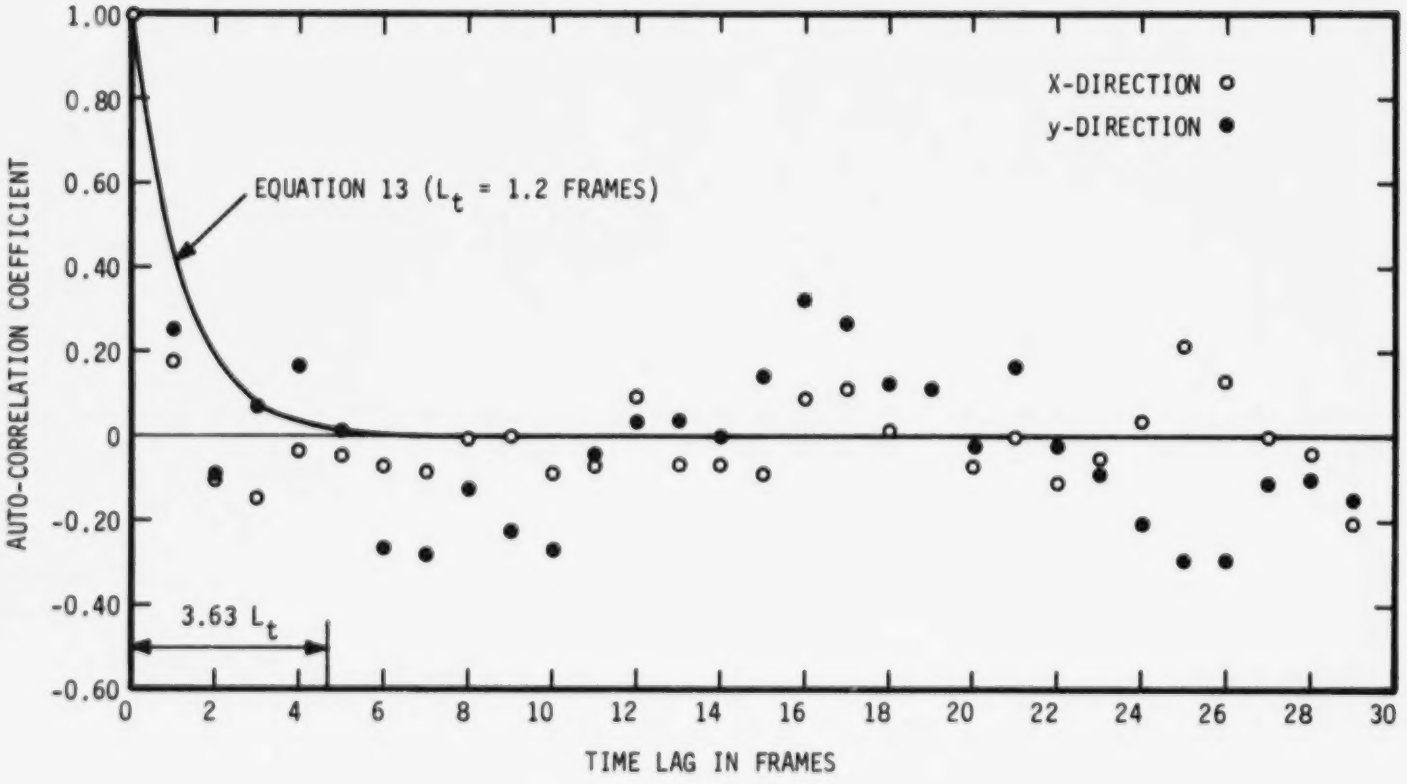
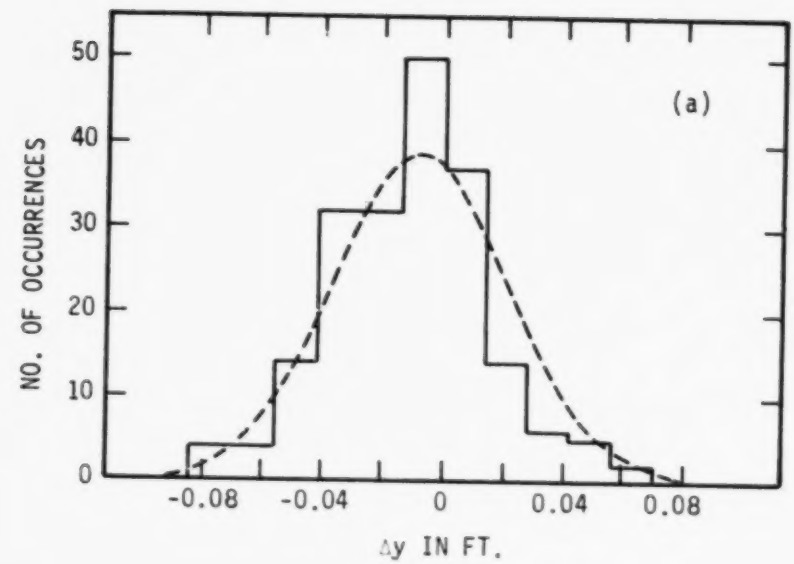


Figure 7. Auto-correlation (3/32-inch Particle).



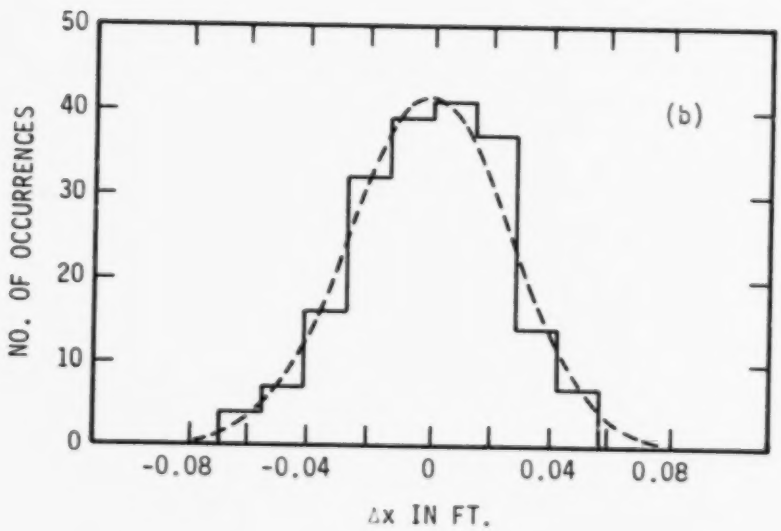


Figure 8. Histograms of Displacement (3/32-inch Particle, n = 3).

$$\overline{\Delta x_n^2} = \overline{(x_{i+n} - x_i)^2} = \frac{1}{p} \sum_{i=1}^{p} (x_{i+n} - x_i)^2 \qquad (19a)$$

and

$$\overline{\Delta y_n^2} = \overline{(y_{i+n} - y_i)^2} = \frac{1}{p} \sum_{i=1}^{p} (y_{i+n} - y_i)^2 \qquad (19b)$$

in which p is the total number of frames in a record of the motion of a single particle. Values of the mean-square displacements are listed in TABLE VI.

TABLE VI

COMPUTED RESULTS

Run No.	d (in)	n (frames)	$\overline{\Delta x^2}(10^3)$ (ft^2)	$\overline{\Delta y^2}(10^3)$ (ft^2)	Average x 10^3 (ft^2)	L_t (sec)	$\epsilon(10^3)$ (ft^2/sec)	$\sqrt{\overline{u^2}}$ (fps)	$\lambda(10^2)$ (ft)
16	3/32	1	0.195	0.190	0.193	0.075	3.36	0.212	1.58
		2	0.515	0.506	0.511				
		3	0.890	0.831	0.861				
		4	1.295	1.154	1.225				
		6	2.183	1.867	2.025				
		8	3.145	2.490	2.817				
		10	4.262	3.155	3.709				
		15	7.323	4.448	5.886				
		20	10.267	5.539	7.903				
		25	12.960	6.175	9.568				
		30	15.788	6.035	10.912				
		40	25.201	6.896	16.049				
		50	35.153	10.018	22.586				
15	5/32	1	0.179	0.151	0.165	0.075	3.41	0.213	1.60
		2	0.511	0.437	0.474				
		3	0.919	0.784	0.852				
		4	1.275	1.109	1.192				
		6	2.036	1.918	1.977				
		8	2.946	2.807	2.877				
		10	3.849	3.841	3.845				
16	7/32	1	0.197	0.153	0.175	0.0541	2.76	0.226	1.22
		2	0.553	0.437	0.495				
		3	0.933	0.780	0.856				
		4	1.371	1.089	1.230				
		6	2.162	1.693	1.927				
		8	2.983	2.172	2.577				
		10	3.944	2.573	3.258				
15	9/32	1	.162	.149	.156	0.075	3.72	0.223	1.67
		2	.493	.458	.476				
		3	.900	.825	.863				
		4	1.380	1.246	1.313				
		6	2.359	2.087	2.223				
		8	3.411	2.890	3.151				
		10	4.558	3.657	4.108				
16	3/8	1	.104	.119	.112	0.075	2.20	0.171	1.28
		2	.289	.361	.325				
		3	.480	.660	.570				

(Continued)

TABLE VI (Continued)

COMPUTED RESULTS

Run No.	d (in)	n (frames)	$\overline{\Delta x^2}(10^3)$ (ft^2)	$\overline{\Delta y^2}(10^3)$ (ft^2)	Average x 10^3 (ft^2)	L_t (sec)	$\epsilon(10^3)$ (ft^2/sec)	$\sqrt{\overline{u^2}}$ (fps)	$\lambda(10^2)$ (ft)
		4	.654	.968	.811				
		6	1.035	1.663	1.349				
		8	1.405	2.374	1.890				
		10	1.753	3.142	2.448				
15	1/2	1	.054	.051	.0525	0.075	0.80	0.103	0.77
		2	.140	.143	.1415				
		3	.203	.229	.2160				
		4	.254	.316	.2850				
		6	.441	.569	.5050				
		8	.589	.799	.6940				
		10	.750	1.006	.8780				

The mean-square displacements as shown in TABLE VI are seen to deviate from each other with increasing lag time (increasing values of n). This result was not expected inasmuch as the nozzle pattern should result in essentially isotropic fluid motion in which $\overline{u}^2 = \overline{v}^2$ and $\overline{\Delta x}^2 = \overline{\Delta y}^2$. The puzzling feature about the deviation of $\overline{\Delta x}^2$ and $\overline{\Delta y}^2$ is that the x and y coordinate system was identical in measuring the coordinates of all particles, yet the mean-square displacements deviate in the opposite sense, as shown by comparison of the mean-square displacements of the 9/32-inch and the 1/2-inch particles in TABLE VI. In the subsequent processing of the data, the motion was assumed to be isotropic with the mean-square displacement in either direction being taken as the mean of the computed values of $\overline{\Delta x}^2$ and $\overline{\Delta y}^2$. The effect of this assumption is to simply combine the mean-square displacements, thereby doubling the number of pieces of data.

3. Diffusion characteristics

a. Coefficient of diffusion. The isotropic diffusion coefficient, ϵ, was determined from the slope of graphs of mean-square displacement versus time. The graphs for the six particles are shown in figure 9. In figure 9 the zero of the $\overline{\Delta x}^2$ axis is shifted for each size in order to separate the points. The abscissa of figure 9 is time expressed frames or units of 1/6 sec. In accordance with equation 14c, the slope of curve is equal to twice the coefficient of diffusion, ϵ, provided that $t > 3.63\ L_t$. Values of ϵ determined from the slopes of the visually located straight lines in figure 9 are listed in TABLE VI.

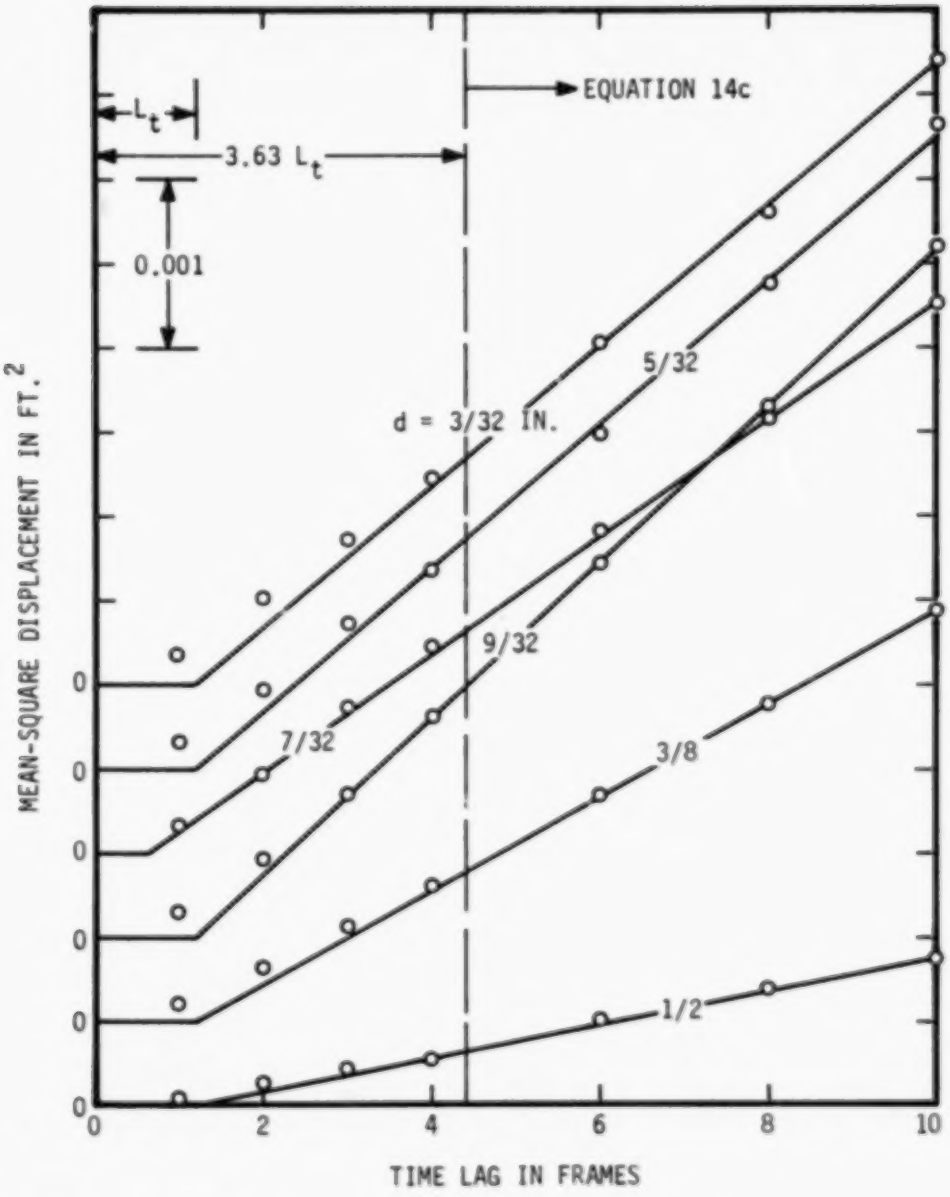


Figure 9. Mean-square Displacement as a Function of Time in Frames.

b. Lagrangian time scale. The lagrangian time scale is defined in equation 10. Since the values of $R(\tau)$ could be determined only at intervals of 1/16 sec, the time interval is too large for meaningful numerical integration of the experimentally determined results. Instead equation 14c and the graphs of mean-square displacement, figure 9, were used to estimate the value of L_t. In the linear equation, equation 14c, $\overline{\Delta x^2} = 0$ when $t = L_t$. This property is utilized to determine graphically the value of L_t, as shown in figure 9. The value, $L_t = 1.2$ frames or 0.075 sec, seemed to be reasonable for all particles except for the 7/32-in-diameter particle. Values of L_t are listed in TABLE VI.

c. Root-mean square velocity. The mean-square velocity can be determined from equation 12, that is, $\overline{u^2} = \epsilon/L_t$, after the values of ϵ and L_t have been determined as described above. Values of the root-mean-square velocity are listed in TABLE VI.

d. Mixing length. Values of the particle mixing-length were computed by means of equation 15, using the previously determined values of L_t and $\sqrt{\overline{u^2}}$. Values of the particle mixing-length, λ, are listed in TABLE VI.

VI. ANALYSIS OF RESULTS

A. Diffusion

1. Theory

The theory of diffusion by continuous movements (II. B.) has been shown to be a good mathematical model for the experiments reported herein. The theoretical solution for the mean-square displacement from the theory of continuous movement and from the earlier theory of discontinuous movements are very similar for time lags sufficiently large for $R(\tau)$ to have decayed to a negligible value. In the range where $R(\tau) \sim 0$, the mean-square-displacement functions versus time interval are parallel straight lines. The curvilimear portion of the continuous-movement function is restricted to time intervals during which $R(\tau) > 0$, for example, in the range $n < 4.36$ frames in figure 9.

The time shift of 1.2 frames shown in figure 9 appears to be reasonable for all particles except the 7/32-inch-diameter particle. The theoretical solution, equation 14c, is based upon an auto-correlation coefficient which decays exponentially, equation 13. Since the time increments are too widely spaced and the measurement of displacement is too coarse to obtain a meaningful value of the Lagrangian time scale by numerical integration of equation 10, the value of L_t was determined from equation 14c and the experimental results as shown in figure 9. The lower limit of equation 14c has been recommended by others 5/ as being $t/L_t = 3.63$. The value of $R(\tau)$ in equation 13 is 0.0264 when $t/L_t = 3.63$, as shown in figure 7.

The pump frequency of 3.60 cycles per second corresponds to 4.44 frames per second. The lower limit of equation 14c at $t = 3.63\ L_t$ corresponds to 4.36 frames. With these values, the lower limit of equation 14c is 1 cycle with the implication that $R(\tau) \sim 0$ after one cycle. Even though the function $R(\tau)$ was assumed to decay exponentially, equation 13, another other type of decay function could have been assumed without effect upon the graphical determination of ϵ since ϵ was evaluated in the linear range, which is the range when $R(\tau) = 0$.

Inasmuch as the pump frequency was the same in Runs 15 and 16, the Lagrangian time scale would be expected to be the same for all particles. This expectation is fulfilled by all particles except for the 7/32-in particle. No explanation for the inconsistent results for the 7/32-in particle has been found.

2. Effect of particle size

The specific object of this study is to determine the effect on particle diffusion of the solid-particle diameter in relationship to a length scale of the turbulent field. Values of particle diffusivity as a function of particle size are shown in figure 10. The solid curve in figure 10 was visually located. Extropolation of the curve back to $d = 0$ is a means of determining fluid diffusivity, ϵ_o. A similar procedure was employed to determine the mixing length of the fluid, λ_o, as shown in figure 11. Using the values of ϵ_o and λ_o to calculate the dimensionless ratios, the ratio of particle-to-fluid diffusivity, ϵ_s/ϵ_o, is shown in figure 12 as a function of the ratio of particle size-to-fluid mixing length, d/λ_o. The solid curve in

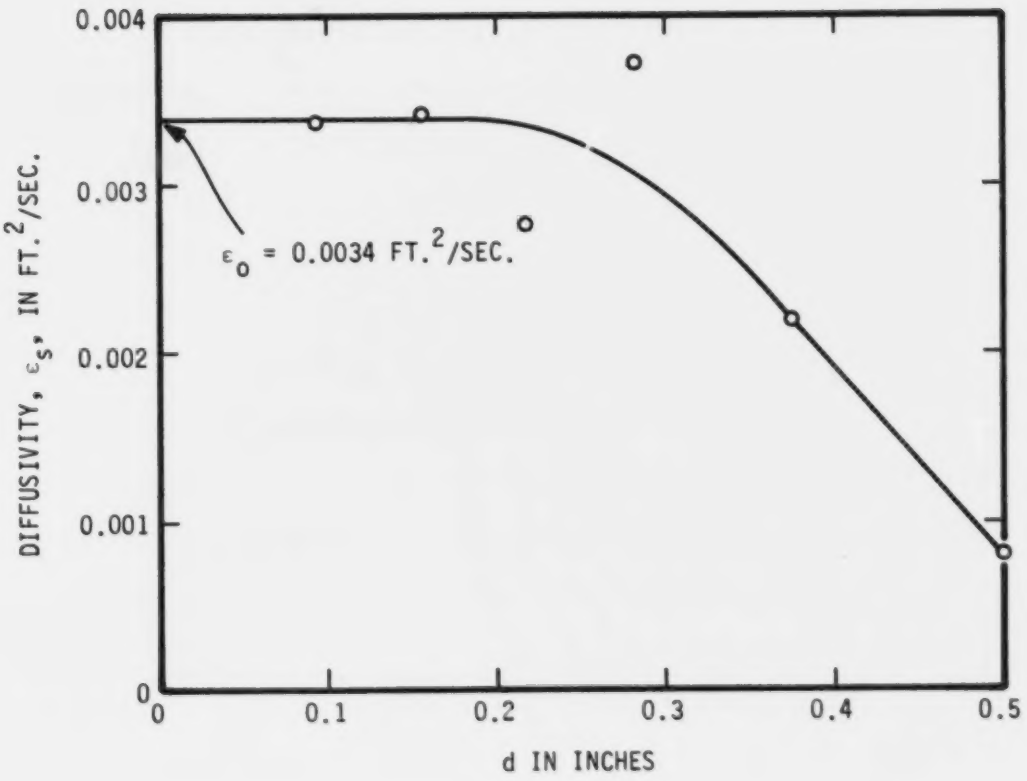


Figure 10. Particle Diffusivity.

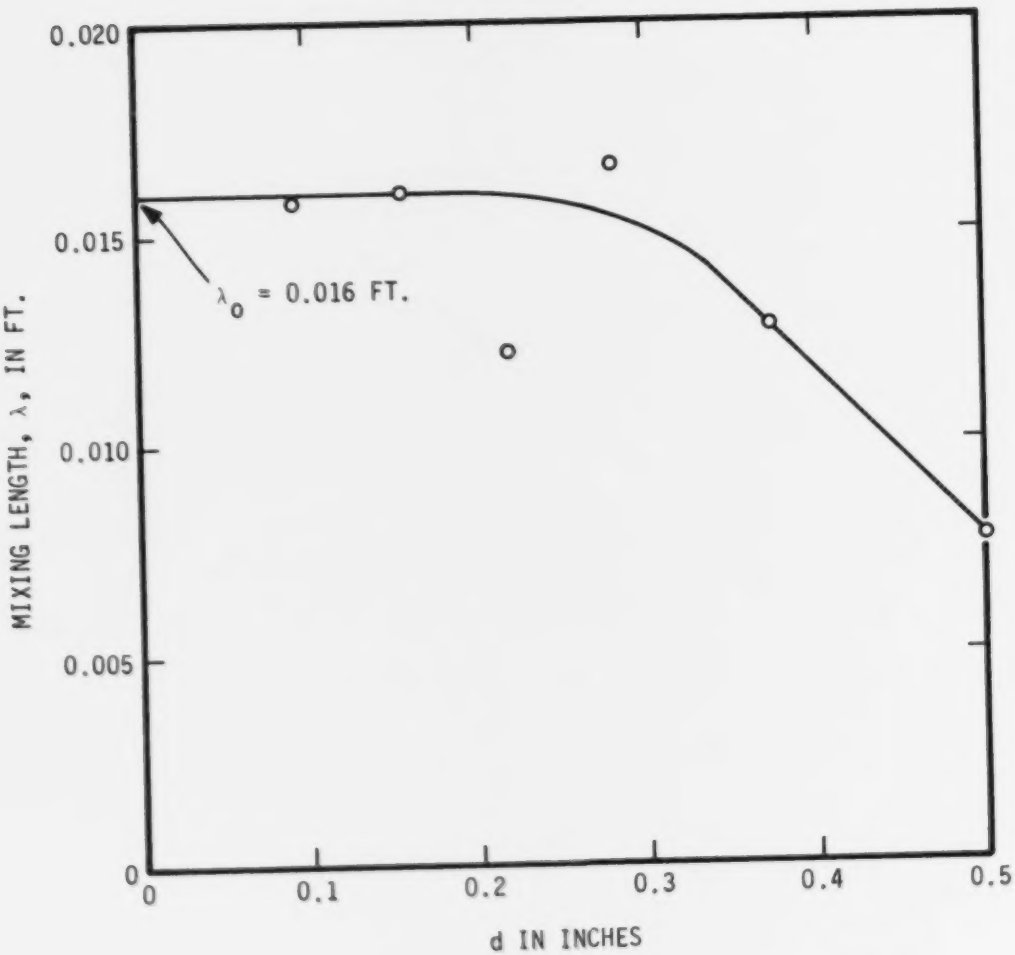


Figure 11. Mixing Length.

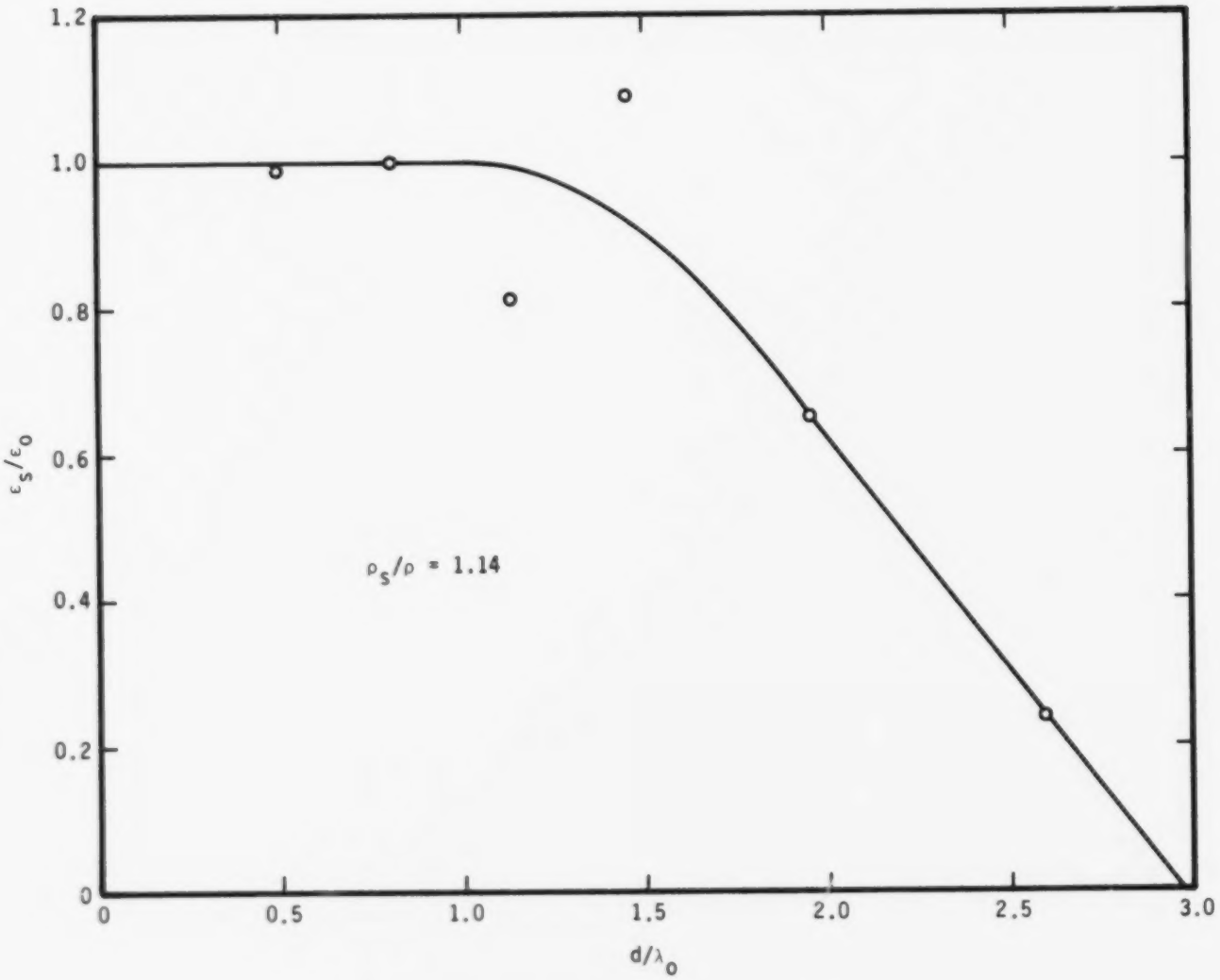


Figure 12. Particle-diffusivity Ratio.

figure 12 was visually fitted to the experimentally determined points. Based on this analysis, $\epsilon_s/\epsilon_o = 1$, if $d < \lambda_o$ and $\epsilon_s/\epsilon_o = 0$ if $d > 3\,\lambda_o$.

3. Effect of inertia

Because the specific gravity of the nylon particles was 1.14 rather than unity, some effect of the density ratio, ρ_s/ρ, might be expected. As related in the INTRODUCTION, the density-ratio effect is vague. According to Carstens' analysis 11/ the value of ϵ_s/ϵ_o would be about 0.86 for the 1/2-inch-diameter particle, whereas, according to Singamsettis' analysis, the value of ϵ_s/ϵ_o would be about 1.3 for the 1/2-inch-diameter particle. About all that can be stated is that the experimental results shown in figure 12 were obtained with a density ratio of 1.14 and that the drastic reduction in the value of ϵ_s/ϵ_o for the 1/2-inch-diameter particle is predominately the effect of the particle-size ratio, d/λ_o.

B. Fluid motion

These experiments were simplified to create a homogeneous isotropic fluid motion without mean motion. Even though the generated fluid motion is capable of diffusing particles, the fluid motion may be so different from naturally generated turbulent motions that the results are of doubtful value. The first author is in the process of analyzing the particle-trajectory data with the object of being much more specific about the nature of fluid motion within the diffusion chamber.

VII. SUMMARY AND CONCLUSIONS

Particle diffusion of six sizes of nylon particles was observed, recorded, and analyzed. The experimental apparatus was designed and the particles were selected to achieve the following:

(a) restriction of the particle motion to a horizontal plane, thereby eliminating the effect of gravity;

(b) elimination of particle-to-particle collisions by observing the motion of widely separated individual particles;

(c) elimination of the effect of particle density by using nearly neutrally buoyant particles; and

(d) a homogeneous and isotropic field of fluid motion in which particle diffusion occurs without mean motion.

The motion of individual particles was recorded on motion-picture film, which was subsequently projected for displacement measurements.

The particle-displacement data were analyzed, using the diffusion theory of continuous movement. The values of the particle diffusivity, ϵ_s, and particle mixing length, λ, as determined from an analysis of the data were plotted as a function of particle diameter, d. By extrapolation of these empirical functions to an infinitely small particle, values of fluid diffusivity, ϵ_o, and fluid mixing length, λ_o, were determined.

On the basis of this analysis, conclusions were drawn as follows:

(a) if $d < \lambda_o$, $\epsilon_s = \epsilon_o$;

(b) if $d > 3\lambda_o$, $\epsilon_s = 0$; and

(c) ϵ_s/ϵ_o continuously decreases in the range $1 < d/\lambda_o < 3$.

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IX. APPENDIX

Particle Coordinates

TABLE A I

COORDINATES OF 3/32 INCH DIAMETER PARTICLES

FRAME NUMBER	X (ft)	Y (ft)	FRAME NUMBER	X (ft)	Y (ft)
26	0.0551	-.0184	66	-.1511	0.0523
27	0.0636	-.0184	67	-.1526	0.0381
28	0.0438	-.0099	68	-.1483	0.0353
29	0.0509	-.0127	69	-.1667	0.0283
30	0.0155	-.0212	70	-.1723	0.0085
31	0.0071	-.0099	71	-.1978	0.0000
32	-.0057	0.0085	72	-.1836	0.0028
33	-.0325	0.0071	73	-.1794	-.0028
34	-.0212	-.0057	74	-.1865	-.0113
35	-.0155	-.0141	75	-.1879	-.0226
36	-.0198	-.0198	76	-.1879	-.0283
37	-.0141	-.0254	77	-.2048	-.0085
38	0.0000	-.0325	78	-.2288	-.0184
39	-.0085	-.0325	79	-.2218	-.0283
40	-.0141	-.0339	80	-.2048	-.0254
41	-.0141	-.0438	81	-.2260	-.0085
42	-.0198	-.0381	82	-.2331	0.0155
43	-.0240	-.0226	83	-.2458	-.0042
44	-.0297	-.0113	84	-.2274	-.0212
45	-.0585	-.0141	85	-.2415	-.0254
46	-.0636	-.0141	86	-.2458	-.0042
47	-.0479	-.0099	87	-.2656	-.0212
48	-.0353	-.0184	88	-.2896	-.0452
49	-.0297	0.0198	89	-.2938	-.0763
50	-.0184	0.0396	90	-.3023	-.0819
51	-.0438	0.0000	91	-.2712	-.1102
52	-.0492	-.0071	92	-.2444	-.1356
53	-.0523	-.0141	93	-.2373	-.1314
54	-.0240	-.0240	94	-.2260	-.1186
55	-.0283	-.0395	95	-.2189	-.1045
56	-.0325	-.0438	96	-.2302	-.1031
57	-.0395	-.0395	97	-.2528	-.0932
58	-.0551	-.0339	98	-.2585	-.0494
59	-.0551	-.0254	99	-.2585	-.0579
60	-.0466	-.0085	100	-.2472	-.0720
61	-.0805	0.0127	101	-.2726	-.0664
62	-.0975	0.0169	102	-.2867	-.0805
63	-.1088	0.0254	103	-.2925	-.0734
64	-.1172	0.0311	104	-.3079	-.0862
65	-.1441	0.0551	105	-.3192	-.0904

(Continued)

TABLE A I

COORDINATES OF 3/32 INCH DIAMETER PARTICLES

FRAME NUMBER	X (ft)	Y (ft)
106	-.3221	-.1017
107	-.3192	-.1116
108	-.3037	-.1215
109	-.2966	-.1017
110	-.3037	-.1088
111	-.2952	-.1172
112	-.2924	-.1116
113	-.3221	-.1017
114	-.3376	-.1003
115	-.3376	-.1102
116	-.3263	-.1102
117	-.2925	-.0989
118	-.2967	-.0890
119	-.2924	-.1045
120	-.2953	-.1300
121	-.2797	-.1342
122	-.2980	-.1408
123	-.3503	-.2147
124	-.3545	-.2020
125	-.3771	-.1950
126	-.3715	-.1992
127	-.3814	-.2302
128	-.3715	-.2387
129	-.3970	-.2557
130	-.4011	-.2542
131	-.4181	-.2472
132	-.4209	-.2288
133	-.3870	-.2133
134	-.3927	-.2020
135	-.3470	-.1992
136	-.4181	-.1740
0	0.0000	0.0735
1	0.0057	0.0492
2	0.0057	0.0692
3	0.0071	0.0706
4	0.0028	0.0819
5	0.0085	0.0565
6	0.0169	0.0438
7	0.0169	0.0325
8	0.0113	0.0466

FRAME NUMBER	X (ft)	Y (ft)
9	0.0014	0.0466
10	-.0169	0.0283
11	-.0198	0.0226
12	-.0198	0.0042
13	-.0226	-.0057
14	-.0268	-.0028
15	-.0268	0.0029
16	-.0367	0.0155
17	-.0395	0.0155
18	-.0424	0.0029
19	-.0438	-.0028
20	-.0466	-.0085
21	-.0410	-.0184
22	-.0381	-.0127
23	-.0395	0.0029
24	-.0254	0.0000
25	-.0226	0.0141
26	-.0254	0.0240
136	0.0071	0.0679
137	0.0071	0.0720
138	0.0042	0.0537
139	0.0099	0.0254
140	0.0169	0.0325
141	0.0000	0.0381
142	0.0099	0.0254
143	0.0042	0.0254
144	-.0085	0.0424
145	-.0169	0.0283
146	-.0254	0.0466
147	-.0283	0.0650
148	-.0311	0.0735
149	-.0311	0.0905
150	-.0311	0.0976
151	-.0367	0.0975
152	-.0353	0.1074
153	-.0226	0.1088
154	-.0283	0.1088
155	-.0353	0.1130
156	-.0621	0.1243
157	-.0890	0.1370

(Continued)

TABLE A I

COORDINATES OF 3/32 INCH DIAMETER PARTICLES

FRAME NUMBER	X (ft)	Y (ft)	FRAME NUMBER	X (ft)	Y (ft)
158	-.1031	0.1469	198	-.3545	0.1243
159	-.0986	0.1524	199	-.3461	0.1285
160	-.0819	0.1639	200	-.3277	0.1356
161	-.0833	0.1594	201	-.2986	0.1300
162	-.0833	0.1540	202	-.3037	0.1300
163	-.0890	0.1580	203	-.2980	0.1413
164	-.0890	0.1596	204	-.2825	0.1370
165	-.0890	0.1596	205	-.2924	0.1187
166	-.0946	0.1639	206	-.3079	0.1102
167	-.1085	0.1879	207	-.2881	0.1384
168	-.1329	0.1780	208	-.2726	0.1624
169	-.1495	0.1752	209	-.2684	0.1808
170	-.1780	0.1681	210	-.2470	0.1907
171	-.1766	0.1737	211	-.2500	0.1992
172	-.1495	0.1709	212	-.2204	0.1879
173	-.1681	0.1554	213	-.2472	0.1723
174	-.1681	0.1356	214	-.2585	0.1567
175	-.1681	0.1229	215	-.2557	0.1695
176	-.1737	0.1172	216	-.2514	0.1766
177	-.1766	0.1017	217	-.2557	0.1950
178	-.1922	0.0848	218	-.2557	0.1963
179	-.2020	0.0904	219	-.2500	0.1992
180	-.2218	0.0876	220	-.2472	0.2048
181	-.2218	0.0805	221	-.2415	0.2161
182	-.2246	0.0805	222	-.2204	0.2246
183	-.2514	0.0735	223	-.2175	0.2288
184	-.2472	0.0650	224	-.2260	0.1949
185	-.2514	0.0819	225	-.2076	0.1850
186	-.2585	0.0848	226	-.2274	0.2034
187	-.2740	0.0975	227	-.2218	0.2076
188	-.2783	0.1031	228	-.2218	0.2161
189	-.2853	0.0946	229	-.2316	0.2090
190	-.3051	0.0876	230	-.2076	0.2133
191	-.3192	0.1088	231	-.1907	0.1709
192	-.3291	0.1102	232	-.1879	0.1483
193	-.3362	0.1088	233	-.1554	0.1780
194	-.3432	0.1003	234	-.1257	0.1695
195	-.3432	0.1003	235	-.1356	0.1808
196	-.3390	0.0975	236	-.1497	0.1737
197	-.3475	0.1102	237	-.1427	0.1540

(Continued)

TABLE A I

COORDINATES OF 3/32 INCH DIAMETER PARTICLES

FRAME NUMBER	X (ft)	Y (ft)	FRAME NUMBER	X (ft)	Y (ft)
241	-.1867	-.1794	280	-.2387	-.0607
242	-.1922	-.1850	281	-.2769	-.0836
243	-.1935	-.1935	282	-.2980	-.0494
244	-.1992	-.1963	283	-.3009	-.0410
245	-.2006	-.2105	284	-.2896	-.0452
246	-.2038	-.2274	285	-.2797	-.0523
247	-.2141	-.2401	286	-.2896	-.0720
248	-.2232	-.2359	287	-.2853	-.0892
249	-.2345	-.2359	288	-.2769	-.0878
250	-.2472	-.2316	289	-.2684	-.0593
251	-.2783	-.2345	290	-.2585	-.0607
252	-.2952	-.2105	291	-.2472	-.0450
253	-.3136	-.2119	292	-.2542	-.0563
254	-.3051	-.2288	293	-.2641	-.0777
255	-.3009	-.2429	294	-.2599	-.0947
256	-.3108	-.2456	295	-.2429	-.0791
257	-.3221	-.2740	296	-.2260	-.0763
258	-.3305	-.2867	297	-.2048	-.0791
259	-.3291	-.2918	298	-.1893	-.1144
260	-.3221	-.2995	299	-.1695	-.1328
261	-.3248	-.3221	300	-.1511	-.1413
262	-.3249	-.3148	301	-.1511	-.1511
263	-.3305	-.3418	302	-.1511	-.1610
264	-.3446	-.3418	303	-.1483	-.1653
265	-.3560	-.3348	304	-.1413	-.1695
266	-.3870	-.3305	305	-.1624	-.1639
267	-.3907	-.3079	306	-.1681	-.1794
268	-.3969	-.2896	307	-.1865	-.1865
269	-.4040	-.2881	308	-.1766	-.1963
270	-.3969	-.2918	309	-.1893	-.1794
271	-.4060	-.3037	310	-.2034	-.1639
271	-.1902	-.0949	311	-.2133	-.1639
272	-.2034	-.0734	312	-.2062	-.1596
273	-.1992	-.0664	313	-.2062	-.1497
274	-.2062	-.0636	314	-.2090	-.1455
275	-.2147	-.0565	315	-.2062	-.1639
276	-.2260	-.0593	316	-.2020	-.1695
277	-.2232	-.0763	317	-.2006	-.1624
278	-.2161	-.0805	318	-.2062	-.1469
279	-.2189	-.0763	319	-.2189	-.1356

(Continued)

TABLE A I

COORDINATES OF 3/32 INCH DIAMETER PARTICLES

FRAME NUMBER	X (ft)	Y (ft)	FRAME NUMBER	X (ft)	Y (ft)
320	-.2175	-.1271	360	-.2670	-.0932
321	-.2062	-.1186	361	-.2528	-.0960
322	-.2006	-.1201	362	-.2528	-.1285
323	-.1893	-.1271	363	-.2670	-.1469
324	-.1865	-.1229	364	-.2769	-.1441
325	-.1893	-.1116	365	-.2811	-.1511
326	-.1850	-.0975	366	-.2769	-.1554
327	-.1723	-.1003	367	-.2740	-.1257
328	-.1596	-.1031	367	-.0579	0.0057
329	-.1243	-.1243	368	-.0720	0.0099
330	-.0989	-.1427	369	-.0847	0.0071
331	-.0960	-.1737	370	-.1243	-.0071
332	-.0621	-.1526	371	-.1314	-.0169
333	-.0692	-.1497	372	-.1497	-.0141
334	-.0720	-.1526	373	-.1780	-.0155
335	-.0847	-.1850	374	-.1850	-.0057
336	-.1031	-.1822	375	-.1808	-.0254
337	-.1130	-.1921	376	-.1935	-.0141
338	-.1172	-.1893	377	-.2359	-.0085
339	-.1314	-.2020	378	-.2331	0.0057
340	-.1455	-.2274	379	-.2670	0.0000
341	-.1737	-.2401	380	-.2910	-.0141
342	-.1836	-.2429	381	-.3051	-.0169
343	-.1836	-.2429	382	-.3263	-.0212
344	-.1879	-.2486	383	-.3376	-.0057
345	-.1907	-.2528	384	-.3503	0.0268
346	-.1935	-.2006	385	-.3771	0.0367
347	-.1963	-.1752	386	-.3729	0.0578
348	-.1907	-.1822	387	-.3616	0.0749
349	-.2034	-.1639	388	-.3616	0.0749
350	-.2161	-.1427	389	-.3658	0.0622
351	-.2260	-.1243	390	-.3701	0.0622
352	-.2331	-.1116	391	-.3927	0.0226
353	-.2359	-.1003	392	-.3941	-.0113
354	-.2514	-.0960	393	-.3941	-.0057
355	-.2641	-.0833	394	-.3771	0.0000
356	-.2585	-.0664	431	-.3164	-.1540
357	-.2498	-.0805	432	-.3602	-.1667
358	-.2867	-.1017	433	-.3658	-.1850
359	-.2740	-.1059	434	-.3574	-.1921

(Continued)

TABLE A I

COORDINATES OF 3/32 INCH DIAMETER PARTICLES

FRAME NUMBER	X (ft)	Y (ft)
435	-.3531	-.1978
436	-.3658	-.2048
437	-.3630	-.2090
438	-.3602	-.2189
439	-.3475	-.2246
440	-.3602	-.2232
441	-.3687	-.2147
442	-.3687	-.2175
443	-.3715	-.1836
444	-.3687	-.1497
445	-.3715	-.1328
446	-.3687	-.1441
447	-.3574	-.1582
448	-.3757	-.1624
449	-.3786	-.1624
450	-.3800	-.1681
451	-.3786	-.1752
452	-.3729	-.1808
453	-.3743	-.1850
454	-.3884	-.1992
455	-.4082	-.2020
456	-.4124	-.2048
457	-.4040	-.2062
458	-.3955	-.1893
459	-.3729	-.1893
460	-.3489	-.1695
461	-.3475	-.1695
462	-.3475	-.1737
463	-.3432	-.1921
464	-.3602	-.1780
465	-.3743	-.1639
466	-.3743	-.1596
466	-.0579	0.3404
467	-.0478	0.3178
468	-.0763	0.3023
469	-.0904	0.2797
470	-.0664	0.2825
471	-.0579	0.3037
472	-.0734	0.3206
473	-.0523	0.2938

FRAME NUMBER	X (ft)	Y (ft)
474	-.0636	0.2867
475	-.0734	0.2980
476	-.0960	0.3108
477	-.1116	0.2825
478	-.0904	0.2627
479	-.0734	0.2613
480	-.0636	0.2585
481	-.0537	0.2613
482	-.0494	0.2670
483	-.0537	0.2740
484	-.0593	0.2867
485	-.0579	0.2882
486	-.0565	0.2769
487	-.0650	0.2726
488	-.1031	0.2627
489	-.0932	0.2627
490	-.0918	0.2599
491	-.0819	0.2415
492	-.0777	0.2246
493	-.0904	0.2175
494	-.1031	0.2076
495	-.1130	0.1978
496	-.1088	0.1949
496	-.2090	0.1808
497	-.2062	0.1596
498	-.2034	0.1752
499	-.2246	0.2006
500	-.2302	0.2062
501	-.2218	0.2147
502	-.2302	0.2147
503	-.2062	0.2204
504	-.2020	0.2232
505	-.1949	0.1893
506	-.1836	0.1723
507	-.1695	0.1653
508	-.1427	0.1540
509	-.1427	0.1413
510	-.1427	0.1413
511	-.1328	0.1469
512	-.1497	0.1144

(Continued)

TABLE AI

COORDINATES OF 3/32 INCH DIAMETER PARTICLES

FRAME NUMBER	X (ft)	Y (ft)	FRAME NUMBER	X (ft)	Y (ft)
513	-.1681	0.0876	523	-.1554	0.0862
514	-.1737	0.0749	524	-.1568	0.1031
515	-.1808	0.0763	525	-.1554	0.1017
516	-.1737	0.0749	526	-.1695	0.1059
517	-.1681	0.0777	527	-.1907	0.1116
518	-.1356	0.0777	528	-.1949	0.1187
519	-.1229	0.0890	529	-.2119	0.1356
520	-.1328	0.0876	530	-.2062	0.1356
521	-.1342	0.0791	531	-.1865	0.1427
522	-.1398	0.0791	532	-.1766	0.1653
533	-.1554	0.1865			

(Concluded)

TABLE A II

COORDINATES OF 5/32 INCH DIAMETER PARTICLES

FRAME NUMBER	X (ft)	Y (ft)	FRAME NUMBER	X (ft)	Y (ft)
45	-.2062	-.0523	85	-.3644	-.0537
46	-.2105	-.0509	86	-.3644	-.0537
47	-.2105	-.0452	87	-.3899	-.0395
48	-.2429	-.0395	88	-.4026	-.0198
49	-.2429	-.0523	89	-.4011	-.0254
50	-.2514	-.0706	90	-.3899	-.0494
51	-.2486	-.0763	91	-.4026	-.0507
52	-.2514	-.0777	92	-.3899	-.0791
53	-.2485	-.0847	93	-.4096	-.0862
54	-.2444	-.0847	94	-.4336	-.0791
55	-.2415	-.0847	95	-.4336	-.0720
56	-.2514	-.0876	96	-.4492	-.0621
57	-.2571	-.1017	97	-.4435	-.0565
58	-.2684	-.1102	98	-.4181	-.0424
59	-.2754	-.1102	99	-.4124	-.0395
60	-.2684	-.0989	100	-.4110	-.0452
61	-.2613	-.0791	101	-.4153	-.0565
62	-.2542	-.0650	102	-.4266	-.0424
63	-.2486	-.0636	103	-.4322	-.0254
64	-.2485	-.0636	104	-.4379	-.0127
65	-.2472	-.0551	105	-.4449	-.0057
66	-.2232	-.0650	106	-.4605	-.0113
67	-.1921	-.0650	107	-.4746	-.0367
68	-.1908	-.0734	108	-.4788	-.0410
69	-.1836	-.0791	109	-.4774	-.0395
70	-.2373	-.0960	110	-.4492	-.0113
71	-.2458	-.0749	111	-.4506	-.0141
72	-.2627	-.0283	112	-.4647	-.0452
73	-.2797	-.0042	113	-.4732	-.0636
74	-.2938	0.0000	114	-.4972	-.0805
75	-.3108	-.0071	115	-.5156	-.0890
76	-.3079	0.0000	116	-.5226	-.0960
77	-.3023	0.0028	117	-.5226	-.1031
78	-.3135	-.0014	118	-.5170	-.1356
79	-.3235	0.0014	119	-.5198	-.1384
80	-.3390	-.0057	120	-.5141	-.1441
81	-.3277	0.0099	121	-.4901	-.1526
82	-.3348	0.0057	122	-.4633	-.1582
83	-.3475	-.0283	123	-.4534	-.1455
84	-.3560	-.0480	124	-.4873	-.1271

(Continued)

TABLE A II

COORDINATES OF 5/32 INCH DIAMETER PARTICLES

FRAME NUMBER	X (ft)	Y (ft)	FRAME NUMBER	X (ft)	Y (ft)
125	-.5028	-.1441	164	-.0960	-.0706
126	-.5057	-.1554	165	-.0932	-.0678
127	-.4859	-.1540	166	-.0946	-.1003
128	-.4774	-.1413	167	-.0791	-.1229
129	-.4873	-.1384	168	-.0664	-.1328
130	-.5127	-.1427	169	-.0650	-.1413
131	-.5014	-.1469	170	-.0607	-.1384
132	-.5127	-.1356	171	-.0551	-.1540
133	-.5198	-.1370	172	-.0509	-.1540
134	-.5085	-.1469	173	-.0424	-.1483
135	-.4958	-.1596	174	-.0339	-.1398
136	-.5127	-.1356	175	-.0297	-.1413
137	-.5000	-.1497	176	-.0466	-.1257
138	-.5184	-.1526	177	-.0537	-.1243
139	-.5113	-.1526	178	-.0452	-.1328
140	-.5085	-.1441	179	-.0452	-.1413
141	-.5198	-.1370	180	-.0480	-.1540
142	-.5127	-.1370	181	-.0367	-.1469
143	-.4944	-.1554	182	-.0254	-.1441
144	-.4986	-.1554	183	-.0198	-.1356
145	-.5156	-.1356	184	-.0198	-.1300
146	-.5198	-.1455	185	-.0424	-.1384
147	-.5127	-.1554	186	-.0621	-.1469
148	-.4986	-.1554	187	-.0734	-.1497
149	-.4944	-.1342	188	-.0734	-.1497
150	-.4944	-.1300	189	-.0339	-.1469
151	-.4902	-.1413	190	-.0480	-.1526
152	-.4746	-.1526	191	-.0650	-.1540
153	-.4746	-.1526	192	-.0565	-.1582
153	-.0480	0.0155	193	-.0509	-.1596
154	-.0593	0.0057	194	-.0353	-.1511
155	-.0763	0.0014	195	-.0169	-.1526
156	-.0833	0.0000	196	-.0113	-.1596
157	-.0962	-.0028	197	-.0184	-.1653
158	-.0847	-.0226	198	-.0212	-.1469
159	-.0749	-.0410	199	-.0113	-.1300
160	-.0678	-.0395	200	0.0085	-.1158
161	-.0749	-.0339	201	0.0198	-.1130
162	-.0847	-.0452	202	0.0198	-.1215
163	-.0791	-.0621	203	0.0184	-.1356

(Continued)

TABLE A II

COORDINATES OF 5/32 INCH DIAMETER PARTICLES

FRAME NUMBER	X (ft)	Y (ft)
204	0.0113	-.1384
205	-.0113	-.1370
206	0.0014	-.1497
207	0.0240	-.1596
208	0.0339	-.1653
209	0.0367	-.1695
210	0.0085	-.1639
211	-.0141	-.1271
212	-.0254	-.1356
213	-.0339	-.1398
214	-.0311	-.1441
215	-.0339	-.1624
216	-.0367	-.1780
217	-.0311	-.1850
218	-.0311	-.1949
219	-.0311	-.2006
220	-.0367	-.2105
221	-.0537	-.2048
222	-.0791	-.2034
223	-.1116	-.1978
224	-.1300	-.2175
225	-.1441	-.2204
226	-.1526	-.2204
227	-.1582	-.2302
228	-.1582	-.2429
229	-.1540	-.2571
230	-.1554	-.2599
231	-.1497	-.2613
232	-.1497	-.2684
233	-.1624	-.2769
234	-.1709	-.2825
235	-.1865	-.3023
236	-.2147	-.3023
237	-.2429	-.3192
238	-.2571	-.3334
239	-.2627	-.3418
240	-.2599	-.3503
241	-.2825	-.3729
242	-.3136	-.3842
243	-.3277	-.3729
244	-.3390	-.3673
245	-.3432	-.3743
246	-.3461	-.3701
247	-.3616	-.3630
248	-.3616	-.3630
248	-.3065	-.0029
249	-.3065	-.0240
250	-.3192	-.0198
251	-.3362	-.0029
252	-.3475	-.0029
253	-.3630	-.0057
410	-.2797	0.3023
411	-.2839	0.2911
412	-.2825	0.2740
413	-.2641	0.2839
414	-.2571	0.2882
415	-.2740	0.2939
416	-.2881	0.2882
417	-.2783	0.3023
418	-.2740	0.3051
419	-.2712	0.2825
420	-.2797	0.2585
421	-.2939	0.2543
422	-.2740	0.2571
423	-.2712	0.2599
424	-.2712	0.2599
425	-.2769	0.2627
426	-.2881	0.2684
427	-.3023	0.2754
428	-.3093	0.2867
429	-.3079	0.2783
430	-.2966	0.2769
431	-.2953	0.2699
432	-.2924	0.2882
433	-.3023	0.2939
434	-.3093	0.2670
435	-.3249	0.2599
437	-.3602	0.2882
438	-.3560	0.2952
439	-.3616	0.2924

(Continued)

TABLE A II

COORDINATES OF 5/32 INCH DIAMETER PARTICLES

FRAME NUMBER	X (ft)	Y (ft)
440	-.3729	0.2896
441	-.3969	0.2924
442	-.3997	0.2797
443	-.2331	0.2119
443	-.2401	0.2204
444	-.2444	0.2430
445	-.2472	0.2413
446	-.2542	0.2670
447	-.2514	0.2769
448	-.2486	0.2939
449	-.2514	0.3051
450	-.2542	0.3221
451	-.2571	0.3334
452	-.2585	0.3263
453	-.2542	0.3206
454	-.2528	0.3065
455	-.2542	0.3023
456	-.2585	0.3164
457	-.2557	0.2924
458	-.2599	0.2585
459	-.2456	0.2444
460	-.2726	0.2458
461	-.2839	0.2472
462	-.2797	0.2472
463	-.2698	0.2684
464	-.2952	0.2698
465	-.3109	0.2656
466	-.3178	0.2684
467	-.3277	0.2754
468	-.3249	0.2952
469	-.3235	0.3206
470	-.3221	0.3475
471	-.3390	0.3517
472	-.3545	0.3544
473	-.3701	0.3673
474	-.3828	0.3461
475	-.3616	0.3461
476	-.3588	0.3560
477	-.3644	0.3743
478	-.3715	0.3870
479	-.3870	0.3900
480	-.3997	0.3743
481	-.3997	0.3743
482	-.3870	0.3644
483	-.3927	0.3418
484	-.4082	0.3334
485	-.4153	0.3249
486	-.4153	0.3136
487	-.4209	0.3249
488	-.4350	0.3221
489	-.4463	0.3164
490	-.4548	0.3093
491	-.4548	0.2995
492	-.4548	0.2825
493	-.4576	0.2712
493	0.1102	0.0848
494	0.0706	0.0749
495	0.0367	0.0579
496	0.0240	0.0593
497	0.0240	0.0466
498	0.0184	0.0466
499	0.0254	0.0254
500	0.0198	0.0198
501	-.0099	0.0254
502	-.0452	0.0396
503	-.0452	0.0396
504	-.0523	0.0424
505	-.0523	0.0466
506	-.0593	0.0353
507	-.0650	0.0184
508	-.0579	0.0099
509	-.0480	0.0127
510	-.0283	0.0254
511	-.0367	0.0311
512	-.0395	0.0381
513	-.0381	0.0452
514	-.0452	0.0353
515	-.0537	0.0283
516	-.0438	0.0353
517	-.0678	0.0184

(Continued)

TABLE A II

COORDINATES OF 5/32 INCH DIAMETER PARTICLES

FRAME NUMBER	X (ft)	Y (ft)	FRAME NUMBER	X (ft)	Y (ft)
560	-.2966	0.1370	600	-.2911	-.0127
561	-.2995	0.1328	601	-.2881	-.0254
562	-.2938	0.1229	602	-.2966	-.0424
563	-.2924	0.1215	603	-.2938	-.0480
564	-.3051	0.1172	604	-.2797	-.0452
565	-.3065	0.1201	605	-.2811	-.0636
566	-.2938	0.1229	606	-.2896	-.1102
567	-.2924	0.1187	607	-.2938	-.1243
568	-.2712	0.1130	608	-.2896	-.1356
569	-.2712	0.1130	609	-.2881	-.1441
570	-.2740	0.1201	610	-.2811	-.1469
571	-.2627	0.1300	611	-.2811	-.1469
572	-.2528	0.1356	612	-.3221	-.1469
573	-.2429	0.1384	613	-.3221	-.1709
574	-.2359	0.1413	614	-.3432	-.1907
575	-.2274	0.1469	615	-.3517	-.2119
576	-.2204	0.1398	616	-.3644	-.2260
577	-.2373	0.1469	617	-.3786	-.2331
578	-.2246	0.1158	618	-.3955	-.2359
579	-.2331	0.1031	619	-.4252	-.2260
580	-.2175	0.0862	620	-.4379	-.2133
581	-.1978	0.0749	865	0.1144	0.1752
582	-.1936	0.0664	866	0.1215	0.1794
583	-.1794	0.0523	867	0.1088	0.1822
584	-.1737	0.0523	868	0.1031	0.1907
585	-.1907	0.0381	869	0.1144	0.2006
586	-.2119	0.0127	870	0.1088	0.1950
587	-.2315	-.0085	871	0.1187	0.1723
588	-.2274	-.0226	872	0.1483	0.1681
589	-.2429	-.0353	873	0.1681	0.1582
590	-.2514	-.0381	874	0.1681	0.1483
591	-.2783	-.0240	875	0.1511	0.1469
592	-.2924	-.0367	876	0.1441	0.1510
593	-.2853	-.0339	877	0.1356	0.1539
594	-.2740	-.0452	878	0.1342	0.1639
595	-.2571	-.0452	879	0.1342	0.1639
596	-.2486	-.0353	880	0.1300	0.1568
597	-.2458	-.0311	881	0.1215	0.1624
598	-.2302	-.0311	882	0.1356	0.1624
599	-.2571	-.0155	883	0.1144	0.1780

(Continued)

TABLE A II

COORDINATES OF 5/32 INCH DIAMETER PARTICLES

FRAME NUMBER	X (ft)	Y (ft)	FRAME NUMBER	X (ft)	Y (ft)
884	0.1116	0.1963	865	0.4280	0.1413
885	0.1172	0.1907	866	0.4209	0.1328
886	0.1201	0.1822	867	0.4238	0.1370
887	0.1427	0.1893	868	0.4238	0.1370
888	0.1356	0.1766	869	0.4209	0.1328
889	0.1342	0.1950	870	0.4082	0.1300
890	0.1328	0.1950	871	0.3814	0.1003
891	0.1384	0.1822	872	0.3771	0.0622
892	0.1300	0.1709	873	0.3800	0.0494
893	0.0932	0.1794	874	0.3757	0.0565
894	0.0848	0.1907	875	0.3786	0.0720
895	0.0805	0.1978	876	0.3800	0.0848
896	0.0833	0.2076	877	0.3687	0.0862
897	0.0932	0.2345	878	0.3348	0.0720
898	0.0989	0.2317	879	0.3164	0.0650
899	0.1201	0.2288	880	0.3065	0.0565
900	0.1356	0.2232	881	0.2896	0.0565
901	0.1384	0.2147	882	0.2839	0.0551
902	0.1413	0.2175	883	0.2896	0.0523
903	0.1427	0.1949	884	0.2797	0.0551
904	0.1554	0.1639	885	0.2769	0.0636
905	0.1554	0.1328	886	0.2641	0.0607
906	0.1554	0.1271	887	0.2500	0.0607
907	0.1314	0.0946	888	0.2373	0.0706
908	0.1243	0.0819	889	0.2260	0.0862
909	0.1187	0.0777	890	0.2119	0.0833
910	0.1059	0.0720	891	0.1979	0.0763
911	0.0706	0.0579	892	0.1653	0.0706
912	0.0494	0.0396	893	0.1398	0.0692
913	0.0494	0.0184	894	0.1257	0.0749
914	0.0607	0.0014	895	0.1172	0.0777
915	0.0593	-.0071	896	0.1074	0.0791
916	0.0438	-.0113	897	0.1003	0.0819
917	0.0452	-.0184	898	0.0876	0.0706
918	0.0113	-.0127	899	0.0396	0.0720
919	-.0226	-.0127	900	0.0169	0.0777
920	-.0395	-.0155	901	0.0057	0.0791
921	-.0509	-.0127	902	0.0028	0.0452
922	-.0523	0.0000	903	0.0028	0.0169
923	-.0509	0.0113	904	-.0113	-.0028

(Continued)

TABLE A II

COORDINATES OF 5/32 INCH DIAMETER PARTICLES

FRAME NUMBER	X (ft)	Y (ft)	FRAME NUMBER	X (ft)	Y (ft)
905	-.0311	0.0000	1061	-.2331	0.0932
906	-.0155	0.0169	1062	-.2571	0.0848
907	-.0198	0.0494	1063	-.2458	0.0749
908	-.0268	0.0664	1064	-.2387	0.0650
909	-.0353	0.0749	1065	-.2359	0.0593
910	-.0494	0.0763	1066	-.2966	0.0509
911	-.0621	0.0749	1067	-.2500	0.0551
912	-.0678	0.0720	1068	-.2698	0.0396
913	-.0904	0.0664	1069	-.2966	0.0735
914	-.1074	0.0509	1070	-.2966	0.0523
915	-.1074	0.0509	1071	-.3150	0.0480
916	-.1102	0.0537	1072	-.3164	0.0269
917	-.1215	0.0579	1073	-.3334	0.0184
918	-.1257	0.0932	1074	-.3136	0.0155
919	-.1285	0.0932	1075	-.3122	0.0297
920	-.1483	0.0848	1076	-.3221	0.0311
921	-.1526	0.0678	1077	-.3390	0.0212
922	-.1483	0.0537	1078	-.3432	0.0000
923	-.1441	0.0452	1079	-.3446	-.0141
1040	-.1850	0.0339	1080	-.3602	0.0014
1041	-.1850	0.0593	1081	-.3602	0.0042
1042	-.1752	0.0664	1082	-.3574	0.0000
1043	-.1695	0.0692	1083	-.3517	-.0113
1044	-.1540	0.0593	1084	-.3475	-.0226
1045	-.1808	0.0622	1085	-.3475	-.0226
1046	-.1893	0.0650	1086	-.3517	-.0113
1047	-.1949	0.0650	1087	-.3658	0.0057
1048	-.1979	0.0579	1088	-.3362	0.0141
1049	-.2161	0.0579	1089	-.3334	0.0339
1050	-.2458	0.0438	1090	-.3560	0.0226
1051	-.2585	0.0480	1091	-.3743	0.0057
1052	-.2726	0.0833	1092	-.3828	0.0057
1053	-.2712	0.0862	1093	-.3856	-.0057
1054	-.2797	0.1074	1094	-.3927	-.0014
1055	-.2867	0.1187	1095	-.4181	-.0071
1056	-.2967	0.1285	1096	-.4294	-.0367
1057	-.2740	0.1370	1097	-.4308	-.0509
1058	-.2613	0.1497	1098	-.4478	-.0509
1059	-.2514	0.1455	1099	-.4478	-.0452
1060	-.2429	0.1116	1100	-.4506	-.0777

(Continued)

TABLE A II

COORDINATES OF 5/32 INCH DIAMETER PARTICLES

FRAME NUMBER	X (ft)	Y (ft)	FRAME NUMBER	X (ft)	Y (ft)
1101	-.8562	-.0946	1141	-.3786	0.1752
1102	-.8534	-.0904	1142	-.3786	0.1808
1103	-.8435	-.0989	1143	-.3630	0.1865
1104	-.8435	-.0791	1144	-.3461	0.1949
1105	-.8605	-.0749	1145	-.3291	0.2076
1106	-.8746	-.0777	1146	-.3249	0.2048
1107	-.8873	-.0692	1147	-.3305	0.1893
1108	-.8944	-.0579	1148	-.3348	0.1949
1109	-.8802	-.0311	1149	-.3348	0.2161
1110	-.8887	0.0000	1150	-.3348	0.2387
1111	-.5000	0.0042	1151	-.3461	0.2500
1112	-.5099	0.0226	1152	-.3602	0.2613
1113	-.5367	0.0353	1128	0.2048	0.3037
1114	-.5240	0.0466	1129	0.1907	0.2952
1115	-.5311	0.0678	1130	0.1907	0.2613
1116	-.5367	0.0819	1131	0.1667	0.2514
1117	-.5311	0.0946	1132	0.1624	0.2472
1118	-.5212	0.1116	1133	0.1695	0.2514
1119	-.5325	0.1158	1134	0.1766	0.2401
1120	-.5184	0.1257	1135	0.1949	0.2189
1121	-.8845	0.1271	1136	0.1822	0.1935
1122	-.8718	0.1314	1137	0.2076	0.1752
1123	-.8902	0.1314	1138	0.2204	0.1681
1124	-.8930	0.1384	1139	0.2260	0.1554
1125	-.5028	0.1455	1140	0.2232	0.1441
1126	-.5085	0.1766	1141	0.2189	0.1356
1127	-.5028	0.2076	1142	0.2175	0.1003
1128	-.8930	0.2161	1143	0.1963	0.0961
1129	-.8817	0.2119	1144	0.1780	0.0975
1130	-.8661	0.1949	1145	0.1681	0.0904
1131	-.8576	0.1766	1146	0.1653	0.0819
1132	-.8633	0.1808	1147	0.1624	0.0763
1133	-.8958	0.2006	1148	0.1526	0.0565
1134	-.8887	0.2232	1149	0.1356	0.0339
1135	-.8732	0.2274	1150	0.1102	0.0184
1136	-.8534	0.2119	1151	0.0989	0.0071
1137	-.8252	0.1850	1154	0.0438	-.0127
1138	-.3899	0.1681	1155	0.0311	-.0494
1139	-.3870	0.1681	1156	0.0424	-.0607
1140	-.3900	0.1709	1157	0.0353	-.0720

(Continued)

TABLE A II

COORDINATES OF 5/32 INCH DIAMETER PARTICLES

FRAME NUMBER	X (ft)	Y (ft)	FRAME NUMBER	X (ft)	Y (ft)
1158	0.0353	-.0763	1198	0.0523	-.1215
1159	0.0367	-.0876	1199	0.0565	-.1186
1160	0.0438	-.0989	1200	0.0593	-.1215
1161	0.0367	-.0989	1201	0.0565	-.1074
1162	0.0537	-.0960	1202	0.0650	0.0961
1163	0.0537	-.0960	1203	0.0622	-.0763
1164	0.0537	-.1186	1204	0.0424	-.0636
1165	0.0565	-.1342	1205	0.0438	-.0607
1166	0.0523	-.1413	1206	0.0494	-.0607
1167	0.0523	-.1483	1207	0.0650	-.0523
1168	0.0339	-.1483	1208	0.0749	-.0650
1169	0.0042	-.1427	1209	0.0918	-.0664
1170	-.0042	-.1229	1210	0.0791	-.0650
1171	0.0000	-.1186	1211	0.0706	-.0650
1172	0.0141	-.1257	1212	0.0918	-.0636
1173	0.0028	-.1158	1213	0.1158	-.0636
1174	0.0141	-.1045	1214	0.1257	-.0593
1175	0.0240	-.0932	1215	0.1314	-.0494
1176	0.0283	-.0932	1216	0.1314	-.0381
1177	0.0381	-.0847	1217	0.1215	-.0028
1178	0.0438	-.0876	1218	0.0876	-.0085
1179	0.0763	-.0636	1219	0.0720	0.0565
1180	0.0961	-.0706	1220	0.0749	0.0537
1181	0.0904	-.0734	1221	0.1045	0.0706
1182	0.0735	-.0791	1222	0.0805	0.0720
1183	0.0763	-.0763	1223	0.0678	0.0777
1184	0.0890	-.0706	1224	0.0622	0.0848
1185	0.0833	-.0678	1225	0.0678	0.0848
1186	0.0706	-.0621	1226	0.0743	0.0819
1187	0.0664	-.0593	1227	0.0833	0.0777
1188	0.0692	-.0749	1228	0.0833	0.0777
1189	0.0904	-.0791	1229	0.0791	0.0848
1190	0.0975	-.0932	1230	0.0819	-.0692
1191	0.1003	-.0904	1231	0.0735	-.0565
1192	0.0791	-.0847	1232	0.0706	-.0367
1193	0.0735	-.0947	1233	0.0678	-.0113
1194	0.0579	-.1059	1234	0.0593	0.0028
1195	0.0509	-.1186	1235	0.0424	0.0085
1196	0.0452	-.1201	1236	0.0424	0.0085
1197	0.0565	-.1257	1237	0.0283	-.0028

(Continued)

TABLE A II

COORDINATES OF 5/32 INCH DIAMETER PARTICLES

FRAME NUMBER	X (ft)	Y (ft)
1238	0.0198	-.0057
1239	0.0000	0.0000
1240	-.0212	0.0198
1241	-.0212	0.0254
1242	-.0311	0.0198
1243	-.0395	0.0226
1244	-.0311	0.0325
1245	-.0734	0.0198
1246	-.1031	0.0184
1247	-.1215	0.0198
1248	-.1356	0.0226
1249	-.1497	0.0650
1250	-.1497	0.0777
1251	-.1582	0.0932
1252	-.1850	0.0989
1253	-.1921	0.1031
1254	-.1949	0.1003
1255	-.2006	0.1271
1256	-.1978	0.1582
1257	-.1850	0.1511
1258	-.1949	0.1469
1259	-.2090	0.1624
1260	-.2161	0.1624
1261	-.2204	0.1639
1262	-.2232	0.1766
1263	-.2288	0.1921
1264	-.2331	0.2048
1265	-.2500	0.2345
1266	-.2613	0.2373
1267	-.2571	0.2232
1268	-.2571	0.2147
1269	-.2571	0.2147
1270	-.2542	0.2147
1271	-.2472	0.2147
1272	-.2514	0.2048
1273	-.2456	0.2006
1274	-.2427	0.1921
1275	-.2599	0.2204
1276	-.2740	0.2458
1277	-.2910	0.2726

FRAME NUMBER	X (ft)	Y (ft)
1278	-.3235	0.2882
1279	-.3362	0.2882
1280	-.3446	0.2882
1281	-.3531	0.2952
1282	-.3658	0.3404
1283	-.3658	0.3376
1284	-.3884	0.3503
1285	-.4195	0.3531
1154	0.1667	0.3390
1155	0.1427	0.3305
1156	0.1483	0.3305
1157	0.1455	0.3291
1158	0.1511	0.3305
1159	0.1610	0.3221
1160	0.1568	0.3305
1161	0.1695	0.2966
1162	0.1822	0.2684
1163	0.1850	0.2571
1164	0.1935	0.2698
1165	0.1935	0.2698
1166	0.2373	0.2331
1167	0.2571	0.2472
1168	0.2599	0.2514
1169	0.2769	0.2514
1170	0.2825	0.2486
1171	0.2712	0.2514
1172	0.2557	0.2401
1173	0.2585	0.2260
1174	0.2656	0.2331
1175	0.2543	0.2373
1176	0.2543	0.2543
1177	0.2486	0.2656
1178	0.2599	0.2825
1179	0.2769	0.2952
1180	0.2896	0.3037
1181	0.2896	0.3164
1182	0.2882	0.3164
1183	0.2627	0.3192
1184	0.2500	0.3418
1185	0.2528	0.3574

(Continued)

TABLE A II

COORDINATES OF 5/32 INCH DIAMETER PARTICLES

FRAME NUMBER	X (ft)	Y (ft)	FRAME NUMBER	X (ft)	Y (ft)
1186	0.2557	0.3517	1188	0.2684	0.3475
1187	0.2599	0.3461	1189	0.2966	0.3503
1190	0.3079	0.3729			

(Concluded)

TABLE A III

COORDINATES OF 7/32 INCH DIAMETER PARTICLES

FRAME NUMBER	X (ft)	Y (ft)	FRAME NUMBER	X (ft)	Y (ft)
0	0.1780	0.1780	40	0.1893	0.1384
1	0.2006	0.1723	41	0.1794	0.1455
2	0.2090	0.1524	42	0.1639	0.1596
3	0.2076	0.1610	43	0.1624	0.1737
4	0.2345	0.1681	44	0.1582	0.1850
5	0.2373	0.1723	45	0.1554	0.1850
6	0.2401	0.1695	46	0.1582	0.1667
7	0.2359	0.1695	47	0.1582	0.1497
8	0.1921	0.1582	48	0.1540	0.1427
9	0.1653	0.1639	49	0.1540	0.1427
10	0.1441	0.1554	50	0.1709	0.1314
11	0.1441	0.1554	51	0.1794	0.1172
12	0.1469	0.1441	52	0.1822	0.1045
13	0.1441	0.1483	53	0.1893	0.0904
14	0.1469	0.1483	54	0.2119	0.0692
15	0.1215	0.1766	55	0.2288	0.0720
16	0.1130	0.1794	56	0.2430	0.0579
17	0.1356	0.1879	57	0.2543	0.0325
18	0.1582	0.1709	58	0.2684	0.0212
19	0.1695	0.1370	59	0.2769	0.0141
20	0.1737	0.1370	60	0.2769	0.0057
21	0.1737	0.1413	61	0.3319	0.0028
22	0.1836	0.1511	62	0.3376	-.0240
23	0.1511	0.1582	63	0.3446	-.0367
24	0.1413	0.1737	64	0.3517	0.0000
25	0.1554	0.1766	65	0.3461	0.0184
26	0.1681	0.1865	66	0.3446	0.0283
27	0.1865	0.1836	67	0.3418	0.0311
28	0.1935	0.1667	68	0.3418	0.0311
29	0.1935	0.1554	69	0.3334	0.0254
30	0.2020	0.1526	70	0.3192	-.0057
31	0.1808	0.1483	71	0.3348	-.0028
32	0.1695	0.1483	72	0.3446	0.0085
33	0.1723	0.1469	73	0.3545	0.0042
34	0.1737	0.1526	74	0.3390	0.0184
35	0.1695	0.1540	75	0.3164	0.0141
36	0.1780	0.1398	76	0.3206	0.0184
37	0.1865	0.1314	77	0.3206	0.0184
38	0.1907	0.1342	78	0.3263	0.0311
39	0.1949	0.1384	79	0.3263	0.0396

(Continued)

TABLE A III

COORDINATES OF 7/32 INCH DIAMETER PARTICLES

FRAME NUMBER	X (ft)	Y (ft)
80	0.3164	0.0396
81	0.3108	0.0396
82	0.3136	0.0381
83	0.3051	0.0226
84	0.3319	0.0198
85	0.3446	0.0268
86	0.3418	0.0367
87	0.3348	0.0381
88	0.3319	0.0198
89	0.3489	-.0085
90	0.3319	-.0169
91	0.3404	-.0240
92	0.3517	-.0311
93	0.3574	-.0283
94	0.3687	-.0240
95	0.3955	-.0141
96	0.4125	0.0000
97	0.3687	0.0071
98	0.3432	0.0042
99	0.3390	-.0057
100	0.3503	-.0057
101	0.3673	0.0127
102	0.3616	0.0169
103	0.3503	0.0042
104	0.3503	-.0057
105	0.3531	-.0155
106	0.3574	-.0184
107	0.3574	-.0141
108	0.3630	-.0198
109	0.3531	0.0071
110	0.3319	0.0141
111	0.3291	0.0240
112	0.3249	0.0283
113	0.3376	0.0325
114	0.3376	0.0381
115	0.3291	0.0254
116	0.3319	0.0240
117	0.3404	0.0198
118	0.3446	0.0240
119	0.3446	0.0240

FRAME NUMBER	X (ft)	Y (ft)
120	0.3446	0.0240
121	0.3503	0.0155
122	0.3560	0.0099
123	0.3715	0.0042
124	0.3644	0.0169
125	0.3390	0.0283
126	0.3192	0.0509
127	0.3136	0.0692
128	0.3065	0.0848
129	0.3023	0.0890
130	0.3023	0.0819
131	0.2995	0.0763
132	0.2882	0.0622
133	0.2825	0.0805
134	0.2684	0.0875
135	0.2359	0.0989
136	0.2472	0.0805
137	0.2415	0.0678
138	0.2415	0.0678
139	0.2288	0.0805
140	0.2430	0.0805
141	0.2486	0.0636
142	0.2599	0.0424
143	0.2712	0.0339
144	0.2769	0.0268
145	0.2896	0.0339
146	0.3108	0.0367
147	0.3432	0.0339
148	0.3531	0.0537
149	0.3531	0.0537
150	0.3489	0.0410
151	0.3489	0.0283
152	.3475	0.0297
153	0.3475	0.0297
154	0.3475	0.0297
155	0.3574	0.0297
156	0.3574	0.0184
157	0.3489	0.0155
158	0.3418	0.0226
159	0.3418	0.0212

(Continued)

TABLE A III

COORDINATES OF 7/32 INCH DIAMETER PARTICLES

FRAME NUMBER	X (ft)	Y (ft)
160	0.3574	0.0184
161	0.3531	0.0113
162	0.3503	-.0085
163	0.3319	0.0071
164	0.3150	0.0057
165	0.3065	0.0014
166	0.3065	0.0014
167	0.3150	-.0028
168	0.3122	0.0113
169	0.3291	0.0155
170	0.3[illegible]4	0.0466
171	0.3348	0.0565
172	0.3277	0.0565
173	0.3051	0.0509
174	0.3122	0.0452
175	0.3206	0.0622
176	0.3235	0.0777
177	0.3235	0.0848
178	0.3150	0.0890
179	0.2811	0.0735
180	0.2373	0.0607
181	0.2218	0.0353
182	0.2076	0.0169
183	0.2076	0.0057
184	0.2076	0.0028
185	0.2006	0.0028
186	0.1794	0.0113
187	0.1511	0.0113
188	0.1667	0.0042
189	0.1865	0.0000
190	0.2006	0.0028
191	0.2076	0.0057
192	0.2147	0.0212
193	0.2161	0.0297
194	0.2204	0.0367
195	0.2076	0.0424
196	0.1893	0.0607
197	0.1794	0.0593
198	0.1653	0.0367
199	0.1695	0.0226
200	0.1766	0.0212
201	0.1836	0.0212
202	0.1836	0.0339
203	0.1766	0.0452
204	0.1709	0.0424
205	0.1709	0.0198
206	0.1582	0.0198
207	0.1483	0.0297
208	0.1172	0.0184
209	0.0904	0.0099
210	0.0876	0.0028
211	0.0918	0.0000
212	0.1215	-.0283
213	0.1243	-.0367
214	0.1074	-.0353
215	0.1074	-.0424
216	0.0890	-.0395
217	0.0678	-.0169
218	0.0593	0.0057
219	0.0523	0.0169
220	0.0438	0.0226
221	0.0057	0.0424
222	-.0057	0.0452
223	-.0071	0.0509
224	-.0212	0.0565
225	-.0297	0.0650
226	-.0381	0.0749
227	-.0494	0.0706
228	-.0890	0.0622
229	-.1045	0.0650
230	-.1229	0.0848
231	-.1229	0.0946
232	-.1398	0.0862
233	-.1540	0.0890
234	-.1511	0.1017
235	-.1511	0.0932
236	-.1639	0.1144
237	-.1511	0.1229
241	-.0876	0.0890
242	-.0876	0.0749

(Continued)

TABLE A III

COORDINATES OF 7/32 INCH DIAMETER PARTICLES

FRAME NUMBER	X (ft)	Y (ft)
283	-.0904	0.0622
284	-.0960	0.0551
285	-.1031	0.0523
286	-.1158	0.0579
287	-.1370	0.0678
288	-.1469	0.0876
289	-.1441	0.1102
290	-.1596	0.1356
291	-.1554	0.1370
292	-.1511	0.1398
293	-.1370	0.1300
294	-.1667	0.1074
295	-.1949	0.1017
296	-.2076	0.1003
297	-.2119	0.1017
298	-.2486	0.0918
299	-.2881	0.1130
300	-.3136	0.1215
301	-.3249	0.1158
302	-.3348	0.1017
303	-.3376	0.1003
304	-.3348	0.0932
305	-.3390	0.0975
306	-.3235	0.0932
307	-.3319	0.1003
308	-.3136	0.1130
309	-.3235	0.1201
310	-.3122	0.1285
311	-.2896	0.1413
312	-.2740	0.1441
313	-.2740	0.1271
314	-.3009	0.1300
315	-.3136	0.1201
316	-.3291	0.1172
317	-.3489	0.1243
318	-.3517	0.1285
319	-.3418	0.1483
320	-.3334	0.1554
321	-.3390	0.1554
322	-.3263	0.1610

FRAME NUMBER	X (ft)	Y (ft)
283	-.3192	0.1554
284	-.3178	0.1483
285	-.3362	0.1384
286	-.3277	0.1356
287	-.3051	0.1469
288	-.3150	0.1300
288	-.0593	0.2076
289	-.0847	0.2133
290	-.1017	0.2161
291	-.1102	0.2289
292	-.1074	0.2599
293	-.0904	0.2882
294	-.0650	0.2980
295	-.0565	0.3093
296	-.0537	0.3192
297	-.0650	0.3249
298	-.0763	0.3277
299	-.0932	0.3362
300	-.1102	0.3461
301	-.1102	0.3461
302	-.1172	0.3475
303	-.1271	0.3461
304	-.1370	0.3390
305	-.1300	0.3291
306	-.1300	0.3079
307	-.1427	0.2882
308	-.1441	0.2797
309	-.1511	0.2797
310	-.1511	0.2726
311	-.1455	0.2698
312	-.1271	0.2740
313	-.1031	0.2867
314	-.0960	0.3108
315	-.1144	0.2980
316	-.1356	0.2924
317	-.1511	0.2882
318	-.1568	0.2825
319	-.1568	0.2769
320	-.1624	0.2712
321	-.1737	0.2740

(Continued)

TABLE A III

COORDINATES OF 7/32 INCH DIAMETER PARTICLES

FRAME NUMBER	X (ft)	Y (ft)	FRAME NUMBER	X (ft)	Y (ft)
322	-.1836	0.2769	362	-.1130	0.1497
323	-.1780	0.2797	363	-.1074	0.1624
324	-.1511	0.2528	364	-.1102	0.1695
325	-.1370	0.2302	365	-.1201	0.1624
326	-.1285	0.2175	366	-.1172	0.1723
327	-.1469	0.2105	367	-.1215	0.1709
328	-.1596	0.1893	368	-.1285	0.1766
329	-.1766	0.1695	369	-.1328	0.1709
330	-.1681	0.1808	370	-.1257	0.1624
331	-.1582	0.1737	371	-.1441	0.1300
332	-.1526	0.1737	372	-.1582	0.1130
333	-.1469	0.1737	373	-.1752	0.1017
334	-.1469	0.1737	374	-.1752	0.1017
335	-.1469	0.1737	375	-.1850	0.1059
336	-.1681	0.1695	376	-.1794	0.1243
337	-.1808	0.1384	377	-.1441	0.1540
338	-.1653	0.1384	378	-.1497	0.1822
339	-.1483	0.1314	379	-.1441	0.1893
340	-.1186	0.1370	380	-.1257	0.1865
341	-.1074	0.1102	381	-.1257	0.1836
342	-.0975	0.0848	382	-.1257	0.1836
343	-.0904	0.0706	383	-.1413	0.1922
344	-.0918	0.0593	384	-.1695	0.1752
345	-.1017	0.0593	385	-.1639	0.1511
346	-.1130	0.0650	386	-.1596	0.1271
347	-.1271	0.0735	387	-.1314	0.1328
348	-.1483	0.0918	388	-.1314	0.1215
349	-.1384	0.0890	389	-.1186	0.1144
350	-.1257	0.0876	390	-.1158	0.1074
351	-.1257	0.0876	391	-.1314	0.0975
352	-.1257	0.0876	392	-.1483	0.1017
353	-.1201	0.0833	393	-.1469	0.0932
354	-.1201	0.0706	394	-.1540	0.1102
355	-.1398	0.0650	431	-.3334	0.0466
356	-.1483	0.0706	432	-.3432	0.0622
357	-.1398	0.0650	433	-.3503	0.0720
358	-.1427	0.0579	434	-.3701	0.0565
359	-.1526	0.0946	435	-.3786	0.0353
360	-.1342	0.1172	436	-.3870	0.0155
361	-.1243	0.1243	437	-.3856	0.0155

(Continued)

TABLE A III

COORDINATES OF 7/32 INCH DIAMETER PARTICLES

FRAME NUMBER	X (ft)	Y (ft)
438	-.3786	0.0226
439	-.3658	0.0283
440	-.3658	0.0311
441	-.3701	0.0452
442	-.3687	0.0480
443	-.3956	0.0509
444	-.3800	0.0367
445	-.3889	0.0226
446	-.3687	0.0198
447	-.3771	0.0169
448	-.3928	0.0085
449	-.3941	-.0071
450	-.3997	-.0198
451	-.4110	-.0283
452	-.4110	-.0424
453	-.4068	-.0452
454	-.4040	-.0523
455	-.4082	-.0466
456	-.4252	-.0353
457	-.4506	-.0141
458	-.4407	-.0494
459	-.4633	-.0692
460	-.4859	-.0946
461	-.5000	-.0904
462	-.5212	-.0946
463	-.5325	-.1144
464	-.5424	-.1229
465	-.5509	-.1116
466	-.5608	-.1116
466	-.2627	0.2218
467	-.2387	0.2430
468	-.2189	0.2302
469	-.2062	0.2020
470	-.1907	0.2006
471	-.1836	0.2105
472	-.1752	0.2218
473	-.1695	0.2161
474	-.2020	0.2105
475	-.2147	0.1780
476	-.2274	0.1695

FRAME NUMBER	X (ft)	Y (ft)
477	-.2359	0.1624
478	-.2387	0.1540
479	-.2444	0.1653
480	-.2472	0.1809
481	-.2331	0.1808
482	-.2189	0.1822
483	-.2147	0.1695
484	-.2415	0.1809
485	-.2415	0.1808
486	-.1935	0.1681
487	-.1780	0.1427
488	-.1695	0.1271
489	-.1582	0.1201
490	-.1398	0.1257
491	-.1511	0.1342
492	-.1455	0.1653
493	-.1427	0.1836
494	-.1370	0.1921
495	-.1441	0.1978
496	-.1441	0.1978
496	-.1314	0.3179
497	-.1088	0.3164
498	-.1059	0.3277
499	-.1102	0.3376
500	-.1130	0.3418
501	-.1172	0.3305
502	-.1172	0.3305
503	-.1186	0.3206
504	-.1243	0.3037
505	-.1526	0.3037
506	-.1554	0.3023
507	-.1624	0.3023
508	-.1526	0.3037
509	-.1229	0.3206
510	-.1285	0.3334
511	-.1370	0.3432
512	-.1582	0.3235
513	-.1582	0.3235
514	-.1667	0.3531
515	-.1667	0.3729

(Continued)

TABLE A III

COORDINATES OF 7/32 INCH DIAMETER PARTICLES

FRAME NUMBER	X (ft)	Y (ft)	FRAME NUMBER	X (ft)	Y (ft)
516	-.1413	0.3701	525	-.1088	0.3277
517	-.1285	0.3630	526	-.1088	0.3390
518	-.1243	0.3560	527	-.0989	0.3390
519	-.1229	0.3475	528	-.0946	0.3446
520	-.1186	0.3108	529	-.1059	0.3122
521	-.1186	0.3109	530	-.0932	0.2882
522	-.1370	0.2995	531	-.0904	0.2769
523	-.1186	0.3122	532	-.0904	0.2670
524	-.11[illegible]	0.3178	533	-.0932	0.2811

(Concluded)

TABLE A IV

COORDINATES OF 9/32 INCH DIAMETER PARTICLES

FRAME NUMBER	X (ft)	Y (ft)	FRAME NUMBER	X (ft)	Y (ft)
45	-.3150	0.2641	85	-.2316	0.3757
46	-.3093	0.2698	86	-.2161	0.3757
47	-.3079	0.2740	87	-.1879	0.3884
48	-.3093	0.2825	88	-.1822	0.3673
49	-.2754	0.2938	89	-.1766	0.3390
50	-.2444	0.2966	90	-.1766	0.3206
51	-.2345	0.3108	91	-.1766	0.3136
52	-.2387	0.3192	92	-.1893	0.3108
53	-.2429	0.3221	93	-.1865	0.3164
54	-.2331	0.3023	94	-.1752	0.3221
55	-.2571	0.3122	95	-.1596	0.3334
56	-.2599	0.3277	96	-.1596	0.3249
57	-.2486	0.3404	97	-.1554	0.3164
58	-.2401	0.3446	98	-.1427	0.3249
59	-.2175	0.3503	99	-.1427	0.3249
60	-.2020	0.3531	100	-.1455	0.3164
61	-.1922	0.3531	101	-.1596	0.3051
62	-.1639	0.3644	102	-.1624	0.3136
63	-.1582	0.3814	103	-.1526	0.3263
64	-.1554	0.3828	104	-.1356	0.3334
65	-.1582	0.3743	105	-.1271	0.3291
66	-.1667	0.3757	106	-.1172	0.3334
67	-.1695	0.3531	107	-.1045	0.3334
68	-.1639	0.3334	108	-.0946	0.3334
69	-.1497	0.3249	109	-.0890	0.3334
70	-.1427	0.3079	110	-.0777	0.3206
71	-.1554	0.2995	111	-.0650	0.3108
72	-.1752	0.2938	112	-.0523	0.2953
73	-.1965	0.2910	113	-.0494	0.2825
74	-.1949	0.2966	114	-.0565	0.2882
75	-.2147	0.3192	115	-.0607	0.2910
76	-.2175	0.3418	116	-.0650	0.2980
77	-.2387	0.3503	117	-.0692	0.3122
78	-.2458	0.3531	118	-.0664	0.3108
79	-.2514	0.3560	119	-.0833	0.3221
80	-.2500	0.3673	120	-.0932	0.3136
81	-.2274	0.3842	121	-.0904	0.3122
82	-.2062	0.3969	122	-.0976	0.3108
83	-.2062	0.3969	123	-.0621	0.3023
84	-.2161	0.3856	124	-.0565	0.3051

(Continued)

TABLE A IV

COORDINATES OF 9/32 INCH DIAMETER PARTICLES

FRAME NUMBER	X (ft)	Y (ft)
125	-.0466	0.3108
126	-.0353	0.3037
127	-.0367	0.3108
128	-.0353	0.3263
129	-.0339	0.3598
130	-.0085	0.3729
131	0.0085	0.3786
132	0.0226	0.3786
133	0.0283	0.3673
134	0.0339	0.3616
135	0.0339	0.3616
136	0.0339	0.3489
137	0.0311	0.3404
138	0.0071	0.3446
139	-.0141	0.3446
140	-.0155	0.3249
141	-.0099	0.3475
142	0.0014	0.3545
143	0.0127	0.3560
144	0.0184	0.3588
145	0.0184	0.3588
146	0.0085	0.3475
147	-.0169	0.3489
148	-.0311	0.3362
149	-.0367	0.3206
150	-.0424	0.3108
151	-.0523	0.3122
152	-.0551	0.3093
153	-.0607	0.3221
154	-.0749	0.3418
155	-.0749	0.3560
156	-.0777	0.3644
157	-.0919	0.3786
158	-.0833	0.3914
159	-.0436	0.3856
160	-.0438	0.3884
161	-.0212	0.3955
162	-.0141	0.3786
163	-.0113	0.3545
164	0.0028	0.3461

FRAME NUMBER	X (ft)	Y (ft)
165	0.0155	0.3390
166	0.0184	0.3305
167	0.0198	0.3319
168	-.0184	0.3390
169	-.0367	0.3503
170	-.0367	0.3616
171	-.0169	0.3729
172	0.0000	0.3616
173	-.0071	0.3602
174	-.0057	0.3701
175	0.0014	0.3842
176	0.0057	0.3983
177	0.0127	0.4068
178	0.0085	0.4181
179	0.0169	0.4252
180	0.0226	0.4322
181	0.0325	0.4322
182	0.0254	0.4379
183	0.0424	0.4548
184	0.0494	0.4633
185	0.0452	0.4803
186	0.0396	0.4803
187	0.0268	0.4675
188	0.0353	0.4633
189	0.0509	0.4675
190	0.0650	0.4788
191	0.0763	0.4873
192	0.0918	0.4788
193	0.0805	0.4590
194	0.0593	0.4393
195	0.0381	0.4294
196	0.0212	0.4308
197	0.0042	0.4308
198	-.0057	0.4435
199	-.0113	0.4675
200	-.0141	0.5000
201	-.0226	0.5382
202	-.0254	0.5353
203	-.0381	0.5311
204	-.0480	0.5353

(Continued)

TABLE A IV

COORDINATES OF 9/32 INCH DIAMETER PARTICLES

FRAME NUMBER	X (ft)	Y (ft)
205	-.0509	0.5368
206	-.0565	0.5396
207	-.0424	0.5537
208	-.0268	0.5452
209	-.0212	0.5311
210	-.0169	0.5113
211	-.0169	0.5099
212	-.0169	0.5170
213	-.0212	0.5170
214	-.0085	0.5170
215	0.0141	0.5311
216	0.0269	0.5466
217	0.0184	0.5509
218	0.0113	0.5424
219	0.0184	0.5269
220	0.0311	0.5297
221	0.0367	0.5509
222	0.0339	0.5466
223	0.0367	0.5339
224	-.0734	0.4351
225	-.0876	0.4407
226	-.0960	0.4464
227	-.1017	0.4379
228	-.1130	0.4407
229	-.1186	0.4336
230	-.1158	0.4294
231	-.1158	0.4209
232	-.1186	0.4393
233	-.1130	0.4619
234	-.1186	0.4633
235	-.1215	0.4619
236	-.1300	0.4435
237	-.1158	0.4336
238	-.1074	0.4280
239	-.1017	0.4209
240	-.1017	0.4322
241	-.1045	0.4520
242	-.1102	0.4746
243	-.1186	0.4774
244	-.1300	0.4803
245	-.1455	0.4774
246	-.1300	0.4803
247	-.1455	0.4774
248	-.1271	0.4887
249	-.1314	0.4916
250	-.1413	0.4944
251	-.1483	0.4916
252	-.1413	0.4944
253	-.1469	0.4972
410	-.1469	0.4972
411	0.1300	0.3346
412	0.1285	0.3263
413	0.1328	0.3136
414	0.1413	0.2939
415	0.1441	0.2911
416	0.1398	0.2754
417	0.1314	0.2698
418	0.1271	0.2726
419	0.1158	0.2754
420	0.1045	0.2740
421	0.0989	0.2698
422	0.0848	0.2684
423	0.0735	0.2740
424	0.0565	0.2726
425	0.0367	0.2585
426	0.0452	0.2585
427	0.0565	0.2585
428	0.0735	0.2585
429	0.0876	0.2571
430	0.1031	0.2557
431	0.1172	0.2500
432	0.1172	0.2373
433	0.1187	0.2274
434	0.1102	0.2006
435	0.0932	0.1780
436	0.0876	0.1639
437	0.0990	0.1624
438	0.1045	0.1526
439	0.1130	0.1554

(Continued)

TABLE A IV

COORDINATES OF 9/32 INCH DIAMETER PARTICLES

FRAME NUMBER	X (ft)	Y (ft)
440	0.1257	0.1752
441	0.1506	0.1836
442	0.1907	0.1809
443	0.2006	0.1794
444	0.1974	0.1752
445	0.1979	0.1610
446	0.1780	0.1469
447	0.1495	0.1413
448	0.1737	0.1558
449	0.1424	0.1441
450	0.1413	0.1257
451	0.1329	0.1300
452	0.1285	0.1329
453	0.1229	0.1384
454	0.1102	0.1483
455	0.1102	0.1483
456	0.0918	0.1752
457	0.1187	0.1752
458	0.1370	0.1567
459	0.1328	0.1469
460	0.1243	0.1568
461	0.1003	0.1582
462	0.0805	0.1596
463	0.0720	0.1667
464	0.0706	0.1709
465	0.0876	0.1427
466	0.0890	0.1158
467	0.0848	0.1130
468	0.0791	0.1017
469	0.0666	0.0945
470	0.0155	0.0932
471	0.0042	0.0876
472	-.0181	0.0904
473	-.0311	0.1045
474	-.0395	0.1130
475	-.0480	0.1271
476	-.0537	0.1342
477	-.0692	0.1639
478	-.0479	0.1922
479	-.0410	0.2076

FRAME NUMBER	X (ft)	Y (ft)
480	-.0353	0.2317
481	-.0311	0.2486
482	-.0339	0.2712
483	-.0339	0.2882
484	-.0395	0.3023
485	-.0410	0.3093
486	-.0494	0.3376
487	-.0650	0.3503
488	-.0692	0.3531
489	-.0692	0.3531
490	-.0819	0.3560
491	-.0678	0.3589
492	-.0268	0.3729
493	-.0155	0.3870
494	-.0155	0.3997
495	-.0127	0.4110
496	-.0141	0.4209
497	0.0000	0.4252
498	0.0297	0.4280
560	0.0819	0.3517
561	0.0735	0.3446
562	0.0650	0.3418
563	0.0607	0.3319
564	0.0579	0.3206
565	0.0579	0.2825
566	0.0805	0.2656
567	0.0975	0.2571
568	0.1201	0.2484
569	0.1427	0.2359
570	0.1596	0.2260
571	0.1723	0.2218
572	0.1780	0.2020
573	0.1808	0.1737
574	0.1921	0.1610
575	0.2076	0.1568
576	0.2133	0.1483
577	0.2034	0.1356
578	0.2034	0.1285
579	0.1723	0.1144
580	0.1511	0.1116

(Continued)

TABLE A IV

COORDINATES OF 9/32 INCH DIAMETER PARTICLES

FRAME NUMBER	X (ft)	Y (ft)
581	0.1511	0.1187
582	0.1511	0.1257
583	0.1483	0.1257
584	0.1384	0.1370
585	0.1495	0.1766
586	0.1441	0.2034
587	0.1384	0.2090
588	0.1356	0.2020
589	0.1441	0.2034
590	0.1540	0.1752
591	0.1737	0.1667
592	0.1865	0.1639
593	0.1978	0.1610
594	0.2020	0.1610
595	0.2141	0.1639
596	0.2219	0.1639
597	0.2260	0.1582
598	0.2288	0.1511
599	0.2317	0.1413
600	0.2345	0.1187
601	0.2302	0.0989
602	0.2161	0.0862
603	0.2076	0.0777
604	0.2090	0.0706
605	0.2090	0.0791
606	0.1936	0.0862
607	0.1653	0.0833
608	0.1483	0.0876
609	0.1324	0.0819
610	0.1074	0.0664
611	0.0819	0.0537
612	0.0692	0.0452
613	0.0692	0.0565
614	0.0692	0.0664
615	0.0749	0.0791
616	0.0537	0.0890
617	0.0353	0.0833
618	0.0283	0.0678
619	0.0169	0.0636
620	0.0127	0.0636

FRAME NUMBER	X (ft)	Y (ft)
621	0.0240	0.0509
622	0.0198	0.0396
623	0.0240	0.0269
624	0.0184	0.0212
625	0.0141	0.0155
626	-.0071	0.0268
627	-.0283	0.0325
628	-.0424	0.0509
629	-.0466	0.0537
630	-.0565	0.0367
631	-.0494	0.0565
632	-.0494	0.0565
633	-.0565	0.0367
634	-.0706	0.0254
635	-.0706	0.0254
636	-.0734	0.0254
637	-.0692	0.0367
638	-.0692	0.0367
639	-.0452	0.0439
640	-.0268	0.0565
641	-.0297	0.0664
642	-.0297	0.0664
643	-.0339	0.0593
644	-.0424	0.0607
645	-.0509	0.0593
646	-.0579	0.0311
647	-.0862	0.0198
648	-.1074	0.0141
649	-.1172	0.0085
650	-.1271	0.0000
651	-.1582	-.0254
652	-.1836	-.0367
653	-.2062	-.0254
654	-.2401	-.0042
655	-.2542	-.0057
656	-.2458	-.0353
657	-.2458	-.0509
658	-.2373	-.0565
659	-.2500	-.0593
660	-.2456	-.0537

(Continued)

TABLE A IV

COORDINATES OF 9/32 INCH DIAMETER PARTICLES

FRAME NUMBER	X (ft)	Y (ft)	FRAME NUMBER	X (ft)	Y (ft)
661	-.2911	-.0593	1051	-.0932	0.3037
662	-.2953	-.0650	1052	-.1130	0.2995
663	-.2925	-.0946	1053	-.1116	0.2726
664	-.2754	-.1172	1054	-.1130	0.2557
665	-.2670	-.1243	1055	-.1102	0.2557
666	-.2627	-.1329	1056	-.0932	0.2500
667	-.2571	-.1384	1057	-.0819	0.2472
668	-.2401	-.1300	1058	-.0706	0.2613
669	-.2048	-.1102	1059	-.0976	0.2783
670	-.1879	-.0989	1070	0.0464	0.2062
671	-.1752	-.0960	1071	0.0464	0.2006
672	-.1653	-.0975	1072	0.0464	0.2006
673	-.1596	-.1031	1073	0.0593	0.2034
674	-.1370	-.1186	1074	0.0480	0.2288
675	-.1271	-.1158	1075	0.0424	0.2543
676	-.1102	-.1074	1076	0.0452	0.2599
677	-.0904	-.1130	1077	0.0464	0.2769
678	-.0805	-.1130	1078	0.0791	0.2952
679	-.0749	-.1144	1079	0.0918	0.3079
680	-.0579	-.1088	1080	0.1074	0.2995
681	-.0494	-.1116	1081	0.1116	0.3065
682	-.0466	-.1059	1082	0.1144	0.3164
683	-.0311	-.0975	1083	0.1243	0.3093
684	-.0199	-.0975	1084	0.1455	0.3037
685	-.0141	-.0932	1085	0.1554	0.3122
686	-.0042	-.0918	1086	0.1596	0.3249
687	0.0085	-.0932	1087	0.1695	0.3389
688	0.0381	-.0946	1088	0.1540	0.3729
689	0.0650	-.0819	1089	0.1493	0.3658
1040	-.0960	0.2105	1090	0.1540	0.3461
1041	-.1003	0.2133	1091	0.1695	0.3376
1042	-.1102	0.2274	1092	0.1780	0.3305
1043	-.0960	0.2359	1093	0.1780	0.3305
1044	-.0763	0.2599	1094	0.1893	0.3560
1045	-.0565	0.2797	1095	0.1695	0.3602
1046	-.0537	0.2966	1096	0.1427	0.3560
1047	-.0407	0.3051	1097	0.1243	0.3771
1048	-.0407	0.3051	1098	0.1144	0.3954
1049	-.0537	0.2896	1099	0.1017	0.3824
1050	-.0706	0.2938	1100	0.0975	0.3928

(Continued)

TABLE A IV

COORDINATES OF 9/32 INCH DIAMETER PARTICLES

FRAME NUMBER	X (ft)	Y (ft)
1101	0.1130	0.3913
1101	0.4407	0.1328
1102	0.4309	0.1413
1103	0.4308	0.1413
1104	0.4280	0.1469
1105	0.4334	0.1356
1106	0.4365	0.1384
1107	0.4294	0.1483
1108	0.4549	0.1427
1109	0.4461	0.1455
1110	0.4718	0.1526
1111	0.4915	0.1695
1112	0.4986	0.1808
1113	0.4746	0.1978
1114	0.4713	0.2161
1115	0.4745	0.2288
1116	0.4675	0.2260
1117	0.4478	0.2317
1118	0.4449	0.2514
1119	0.4365	0.2413
1120	0.4365	0.2413
1121	0.4492	0.2557
1122	0.4534	0.2317
1123	0.4393	0.2042
1124	0.4223	0.1921
1125	0.4223	0.1921
1126	0.4223	0.1921
1127	0.4336	0.2004
1128	0.4591	0.2133
1129	0.4520	0.2105
1130	0.4534	0.2274
1131	0.4449	0.2458
1132	0.4534	0.2529
1133	0.4534	0.2528
1134	0.4407	0.2359
1135	0.4492	0.2472
1136	0.4534	0.2529
1137	0.4405	0.2486
1138	0.4534	0.2274
1139	0.4492	0.2359

FRAME NUMBER	X (ft)	Y (ft)
1140	0.4534	0.2444
1141	0.4405	0.2486
1142	0.4704	0.2486
1143	0.4475	0.2359
1144	0.4449	0.2246
1145	0.4238	0.2105
1146	0.4040	0.1992
1147	0.3955	0.1949
1148	0.3899	0.1921
1149	0.3842	0.1992
1150	0.3900	0.2147
1151	0.3900	0.2500
1152	0.3771	0.2769
1153	0.3545	0.2811
1154	0.3418	0.2811
1155	0.3319	0.2797
1156	0.3419	0.2811
1157	0.3444	0.3051
1158	0.3701	0.3319
1159	0.3955	0.3419
1160	0.4068	0.3334
1161	0.4125	0.3206
1162	0.4223	0.3051
1163	0.4223	0.3051
1164	0.4322	0.2980
1165	0.4322	0.2963
1166	0.4351	0.2783
1167	0.4449	0.2670
1168	0.4421	0.2585
1169	0.4322	0.2528
1170	0.4365	0.2514
1171	0.4478	0.2500
1172	0.4534	0.2373
1173	0.4365	0.2302
1174	0.4504	0.2430
1174	-.1441	0.3334
1175	-.1582	0.3221
1176	-.1595	0.3150
1177	-.1511	0.3164
1178	-.1511	0.3079

(Continued)

TABLE A IV

COORDINATES OF 9/32 INCH DIAMETER PARTICLES

FRAME NUMBER	X (ft)	Y (ft)	FRAME NUMBER	X (ft)	Y (ft)
1179	-.1582	0.3079	1219	-.1257	0.2952
1180	-.1554	0.3178	1220	-.1243	0.3109
1181	-.1526	0.3206	1221	-.1257	0.3051
1182	-.1667	0.2952	1222	-.1356	0.2924
1183	-.1695	0.3079	1223	-.1201	0.2995
1184	-.1737	0.3235	1224	-.1158	0.3164
1185	-.1695	0.3390	1225	-.1130	0.3305
1186	-.1639	0.3446	1226	-.1116	0.3446
1187	-.1695	0.3446	1227	-.1116	0.3531
1188	-.1836	0.3418	1228	-.0946	0.3545
1189	-.1978	0.3446	1229	-.0833	0.3531
1190	-.2105	0.3602	1230	-.0763	0.3531
1191	-.2006	0.3729	1231	-.0650	0.3404
1192	-.1879	0.3673	1232	-.0367	0.3588
1193	-.1794	0.3461	1233	-.0254	0.3814
1194	-.1794	0.3334	1234	-.0141	0.4054
1195	-.1836	0.3206	1235	-.0099	0.4238
1196	-.1836	0.3108	1236	-.0042	0.4421
1197	-.1836	0.3206	1236	0.1003	0.1978
1198	-.1794	0.3206	1237	0.1187	0.2076
1199	-.1723	0.3319	1238	0.1384	0.2119
1200	-.1822	0.3291	1239	0.1526	0.1907
1201	-.1752	0.3376	1240	0.1639	0.1610
1202	-.1596	0.3319	1241	0.1808	0.1469
1203	-.1370	0.3291	1242	0.1808	0.1469
1204	-.1342	0.3206	1243	0.1639	0.1469
1205	-.1441	0.3122	1244	0.1965	0.1723
1206	-.1342	0.3305	1245	0.2048	0.1780
1207	-.1526	0.3108	1246	0.2147	0.1780
1208	-.1667	0.2882	1247	0.2175	0.1709
1209	-.1667	0.2982	1248	0.2105	0.1681
1210	-.1667	0.2853	1249	0.1921	0.1526
1211	-.1709	0.2882	1250	0.1822	0.1300
1212	-.1737	0.2882	1251	0.1808	0.1187
1213	-.1582	0.3122	1252	0.1978	0.1328
1214	-.1427	0.3065	1253	0.1978	0.1328
1215	-.1243	0.3065	1254	0.1780	0.1201
1216	-.1201	0.3065	1255	0.1441	0.1102
1217	-.1285	0.2980	1256	0.1257	0.1243
1218	-.1342	0.2882	1257	0.1144	0.1271

(Continued)

TABLE A IV

COORDINATES OF 9/32 INCH DIAMETER PARTICLES

FRAME NUMBER	X (ft)	Y (ft)	FRAME NUMBER	X (ft)	Y (ft)
1258	0.1045	0.1342	1288	0.0283	0.1639
1259	0.1116	0.1384	1289	0.0155	0.1639
1260	0.1215	0.1285	1290	0.0057	0.1610
1261	0.1215	0.1285	1291	-.0099	0.1596
1262	0.1158	0.1356	1292	-.0099	0.1695
1263	0.1158	0.1511	1293	-.0283	0.1822
1264	0.1342	0.1384	1294	-.0494	0.1822
1265	0.1342	0.1384	1295	-.0466	0.1808
1266	0.1328	0.1441	1296	-.0537	0.1978
1267	0.1300	0.1582	1297	-.0395	0.2189
1268	0.1285	0.1610	1298	-.0466	0.2246
1269	0.1285	0.1610	1299	-.0509	0.2331
1270	0.1031	0.1865	1300	-.0607	0.2331
1271	0.0933	0.2062	1301	-.0720	0.2232
1272	0.0777	0.2189	1302	-.0763	0.2317
1273	0.0805	0.2274	1303	-.0664	0.2472
1274	0.0918	0.2302	1304	-.0862	0.2599
1275	0.0749	0.2062	1305	-.0932	0.2656
1276	0.0706	0.1992	1306	-.0847	0.2684
1277	0.0720	0.1907	1307	-.0763	0.2684
1278	0.0777	0.1949	1308	-.0706	0.2740
1279	0.0948	0.2090	1309	-.0734	0.2825
1280	0.1159	0.2175	1310	-.0805	0.2896
1281	0.1314	0.2175	1311	-.0960	0.2910
1282	0.1314	0.1836	1312	-.0890	0.2825
1283	0.1201	0.1667	1313	-.1017	0.2783
1284	0.0819	0.1653	1314	-.1088	0.2966
1285	0.0735	0.1639	1315	-.1088	0.3023
1286	0.0494	0.1639	1316	-.1088	0.2966
1287	0.0367	0.1653	1317	-.1102	0.2797

(Concluded)

TABLE A V

COORDINATES OF 3/8 INCH DIAMETER PARTICLES

FRAME NUMBER	X (ft)	Y (ft)	FRAME NUMBER	X (ft)	Y (ft)
0	0.2161	-.0763	40	0.3418	-.2387
1	0.2048	-.0763	41	0.3418	-.2331
2	0.2048	-.0706	42	0.3319	-.2175
3	0.2175	-.0636	43	0.3235	-.2090
4	0.2345	-.0593	44	0.3122	-.1949
5	0.2557	-.0636	45	0.3122	-.1949
6	0.2811	-.0791	46	0.3277	-.2006
7	0.3051	-.0847	47	0.3319	-.1893
8	0.3150	-.1003	48	0.3164	-.1737
9	0.3093	-.1243	49	0.3136	-.1780
10	0.3164	-.1243	50	0.3164	-.1893
11	0.3178	-.1328	51	0.3221	-.2034
12	0.3079	-.1511	52	0.3164	-.2034
13	0.3079	-.1766	53	0.3037	-.1921
14	0.3206	-.1992	54	0.3136	-.1978
15	0.3305	-.2204	55	0.3305	-.2076
16	0.3249	-.2175	56	0.3277	-.2006
17	0.3249	-.2090	57	0.3108	-.1949
18	0.3150	-.2006	58	0.2980	-.1855
19	0.3334	-.2105	59	0.2938	-.1893
20	0.3334	-.2105	60	0.3051	-.2062
21	0.3150	-.2006	61	0.2980	-.1992
22	0.3122	-.1907	62	0.3009	-.2119
23	0.3249	-.2048	63	0.3122	-.2246
24	0.3277	-.2090	64	0.3122	-.2288
25	0.3348	-.2119	65	0.3093	-.2359
26	0.3376	-.1978	66	0.2896	-.2331
27	0.3291	-.1794	67	0.2726	-.2415
28	0.3362	-.1893	68	0.2896	-.2500
29	0.3446	-.1907	69	0.2896	-.2500
30	0.3362	-.1935	70	0.2684	-.2444
31	0.3249	-.1992	71	0.2599	-.2415
32	0.3178	-.2090	72	0.2641	-.2444
33	0.3192	-.2175	73	0.2726	-.2500
34	0.3192	-.2204	74	0.2684	-.2542
35	0.3051	-.2062	75	0.2571	-.2429
36	0.3108	-.2133	76	0.2486	-.2514
37	0.3249	-.2246	77	0.2458	-.2627
38	0.3319	-.2331	78	0.2458	-.2740
39	0.3334	-.2429	79	0.2458	-.2938

(Continued)

TABLE A V

COORDINATES OF 3/8 INCH DIAMETER PARTICLES

FRAME NUMBER	X (ft)	Y (ft)
80	0.2486	-.2953
81	0.2458	-.2456
82	0.2274	-.2458
83	0.2317	-.2345
84	0.2585	-.2288
85	0.2498	-.2429
86	0.2925	-.2599
87	0.2982	-.2613
88	0.2925	-.2712
89	0.2456	-.2726
90	0.2498	-.2541
91	0.2681	-.2541
92	0.2583	-.2911
93	0.2359	-.2925
94	0.2260	-.2698
95	0.2006	-.2627
96	0.1965	-.2585
97	0.1908	-.2542
98	0.1908	-.2542
99	0.1554	-.2542
100	0.1441	-.2444
101	0.1370	-.2345
102	0.1257	-.2218
103	0.1300	-.2090
104	0.1257	-.1936
105	0.1158	-.1539
106	0.1114	-.1427
107	0.1187	-.1257
108	0.1384	-.1130
109	0.1370	-.1088
110	0.1370	-.1088
111	0.1257	-.1257
112	0.1285	-.1215
113	0.1384	-.1158
114	0.1441	-.1186
115	0.1384	-.1257
116	0.1427	-.1384
117	0.1526	-.1328
118	0.1526	-.1328
119	0.1681	-.1342
120	0.1836	-.1314
121	0.1737	-.1186
122	0.1582	-.1285
123	0.1568	-.1356
124	0.1524	-.1441
125	0.1681	-.1511
126	0.1723	-.1569
127	0.1695	-.1582
128	0.1780	-.1653
129	0.1752	-.1356
130	0.1624	-.1144
131	0.1568	-.1074
132	0.1469	-.1031
133	0.1413	-.1031
134	0.1384	-.1003
135	0.1300	-.1003
136	0.1158	-.1059
137	0.0918	-.1059
138	0.0777	-.0960
139	0.0777	-.0874
140	0.0833	-.0650
141	0.0833	-.0494
142	0.0819	-.0353
143	0.0720	-.0325
144	0.0743	-.0424
145	0.0763	-.0565
146	0.0735	-.0678
147	0.0763	-.0791
148	0.0763	-.0791
149	0.0763	-.0791
150	0.0833	-.0791
151	0.0819	-.0904
152	0.0819	-.0904
153	0.0918	-.0791
154	0.0819	-.0664
155	0.0735	-.0509
156	0.0636	-.0551
157	0.0650	-.0692
158	0.0777	-.0734
159	0.0777	-.0734

(Continued)

TABLE A V

COORDINATES OF 3/8 INCH DIAMETER PARTICLES

FRAME NUMBER	X (ft)	Y (ft)	FRAME NUMBER	X (ft)	Y (ft)
160	0.0735	-.0734	200	0.0381	0.0819
161	0.0579	-.0734	201	0.0113	0.1045
162	0.0439	-.0734	202	0.0057	0.1133
163	0.0438	-.0706	203	0.0057	0.1133
164	0.0509	-.0679	204	0.0028	0.1187
165	0.0593	-.0720	205	0.0028	0.1187
166	0.0664	-.0550	206	-.0057	0.1303
167	0.0706	-.0565	207	-.0057	0.1383
168	0.0749	-.0269	208	-.0028	0.1449
169	0.0706	-.0269	209	0.0057	0.1582
170	0.0664	-.0297	210	0.0029	0.1511
171	0.0622	-.0494	211	0.0000	0.1610
172	0.0492	-.0550	212	0.0000	0.1610
173	0.0592	-.0962	213	0.0042	0.1794
174	0.0763	-.1017	214	-.0042	0.1794
175	0.0918	-.1017	215	-.0226	0.1794
176	0.1017	-.0932	216	-.0353	0.1822
177	0.0918	-.1017	217	-.0440	0.1963
178	0.0976	-.1017	218	-.0565	0.2147
179	0.1059	-.0933	219	-.0523	0.2373
180	0.0389	-.0734	220	-.0339	0.2585
181	0.0989	-.0734	221	-.0339	0.2656
182	0.0890	-.0890	222	-.0650	0.2571
183	0.0791	-.0890	223	-.0444	0.2599
184	0.0819	-.0749	224	-.0664	0.2724
185	0.0990	-.0452	225	-.0720	0.2754
186	0.0919	-.0181	226	-.0890	0.2656
187	0.0819	0.0124	227	-.0890	0.2656
188	0.0791	0.0226	228	-.0833	0.2839
189	0.0720	0.0293	229	-.0890	0.2934
190	0.0791	0.0226	230	-.0932	0.2995
191	0.0919	0.0226	231	-.1017	0.2995
192	0.0948	0.0339	232	-.1017	0.2995
193	0.0948	0.0381	233	-.0932	0.2995
194	0.0735	0.0367	234	-.0949	0.3079
195	0.0592	0.0226	235	-.1116	0.3291
196	0.0720	0.0339	236	-.1229	0.3291
197	0.0720	0.0339	237	-.1455	0.3179
198	0.0636	0.0339	241	-.0833	0.2995
199	0.0607	0.0537	242	-.0636	0.2995

(Continued)

TABLE A V

COORDINATES OF 3/8 INCH DIAMETER PARTICLES

FRAME NUMBER	X (ft)	Y (ft)	FRAME NUMBER	X (ft)	Y (ft)
243	-.0424	0.2995	283	-.0791	0.3079
244	-.0367	0.3037	284	-.0890	0.3079
245	-.0565	0.3192	285	-.0847	0.3093
246	-.0833	0.3291	286	-.0890	0.3108
247	-.1045	0.3376	287	-.1003	0.3249
248	-.1130	0.3418	288	-.1116	0.3432
249	-.1257	0.3432	289	-.1158	0.3531
250	-.1455	0.3334	290	-.1186	0.3602
251	-.1497	0.3206	291	-.1158	0.3687
252	-.1455	0.3150	292	-.1116	0.3786
253	-.1314	0.3277	293	-.1045	0.3870
254	-.1356	0.3249	294	-.0975	0.3927
255	-.1370	0.3079	295	-.0904	0.4012
256	-.1215	0.3136	296	-.0777	0.4125
257	-.1144	0.3334	297	-.0636	0.4223
258	-.1116	0.3348	298	-.0494	0.4351
259	-.1059	0.3249	299	-.0367	0.4393
260	-.1045	0.3079	300	-.0283	0.4322
261	-.1116	0.2995	301	-.0424	0.4238
262	-.1045	0.2797	302	-.0283	0.4322
263	-.0904	0.2726	303	-.0226	0.4435
264	-.0805	0.2811	304	-.0226	0.4506
265	-.0734	0.2825	305	-.0198	0.4534
266	-.0847	0.2740	306	-.0226	0.4605
267	-.0847	0.2740	307	-.0226	0.4859
268	-.0777	0.2938	308	-.0198	0.5000
269	-.0847	0.3009	309	-.0169	0.5170
270	-.0847	0.3009	310	-.0155	0.5339
271	-.0946	0.3009	311	-.0169	0.5396
272	-.0932	0.3023	311	-.3037	0.1370
273	-.0960	0.3051	312	-.3122	0.1328
274	-.0932	0.3009	313	-.3122	0.1328
275	-.0975	0.3023	314	-.3037	0.1370
276	-.1031	0.2966	315	-.3178	0.1271
277	-.1144	0.2966	316	-.3446	0.1229
278	-.1215	0.3051	317	-.3531	0.1257
279	-.0946	0.3009	318	-.3531	0.1257
280	-.0975	0.3206	319	-.3446	0.1398
281	-.0777	0.3164	320	-.3446	0.1398
282	-.0763	0.3079	321	-.3362	0.1483

(Continued)

TABLE A V

COORDINATES OF 3/8 INCH DIAMETER PARTICLES

FRAME NUMBER	X (ft)	Y (ft)
322	-.3192	0.1511
323	-.3122	0.1524
324	-.3192	0.1455
325	-.3201	0.1370
326	-.3150	0.1382
327	-.2939	0.1455
328	-.2925	0.1511
329	-.2740	0.1455
330	-.2924	0.1356
331	-.2905	0.1569
332	-.3023	0.1481
333	-.3051	0.1909
334	-.3134	0.1936
335	-.3051	0.1909
336	-.3134	0.1921
337	-.3136	0.1949
338	-.3051	0.2105
339	-.3051	0.2260
340	-.3192	0.2514
341	-.3249	0.2712
342	-.3404	0.2882
343	-.3201	0.2905
344	-.3192	0.3051
345	-.3079	0.3249
346	-.3134	0.3221
347	-.3201	0.3122
348	-.3201	0.3122
349	-.3249	0.3221
350	-.3221	0.3348
351	-.3249	0.3348
352	-.3303	0.3249
353	-.2924	0.3461
354	-.2924	0.3461
355	-.2924	0.3461
356	-.2964	0.3221
357	-.2964	0.3051
358	-.3037	0.3108
359	-.3045	0.3122
360	-.3192	0.3108
361	-.3122	0.3108

FRAME NUMBER	X (ft)	Y (ft)
362	-.2980	0.3192
363	-.2981	0.3249
364	-.2939	0.3334
365	-.2939	0.3334
366	-.2952	0.3432
367	-.3065	0.3348
368	-.3235	0.3249
369	-.3235	0.3178
370	-.3178	0.3179
371	-.3023	0.3362
372	-.2966	0.3446
373	-.2966	0.3446
374	-.3023	0.3362
375	-.3023	0.3362
376	-.3079	0.3348
377	-.3334	0.3150
378	-.3334	0.3150
379	-.3334	0.3150
380	-.3249	0.3348
381	-.3362	0.3291
382	-.3517	0.3221
383	-.3644	0.3221
384	-.3771	0.3277
385	-.3771	0.3291
386	-.3913	0.3475
387	-.3927	0.3602
388	-.3997	0.3757
389	-.4110	0.3984
390	-.4082	0.3955
391	-.3983	0.4082
392	-.3786	0.4280
393	-.3616	0.4280
394	-.3616	0.4280
431	0.0650	0.4633
432	0.0650	0.4534
433	0.0537	0.4633
434	0.0410	0.4690
435	0.0325	0.4774
436	0.0381	0.4944
437	0.0537	0.5127

(Continued)

TABLE A V

COORDINATES OF 3/8 INCH DIAMETER PARTICLES

FRAME NUMBER	X (ft)	Y (ft)
438	0.0668	0.5249
439	0.0720	0.5311
440	0.0833	0.5249
441	0.0919	0.5269
442	0.0961	0.5240
443	0.1074	0.5085
444	0.1102	0.4996
445	0.1184	0.4901
446	0.1074	0.4930
447	0.1144	0.4817
448	0.0961	0.4732
449	0.0777	0.4690
450	0.0607	0.4548
451	0.0523	0.4591
446	0.0438	0.5297

FRAME NUMBER	X (ft)	Y (ft)
452	0.0551	0.4633
453	0.0607	0.4774
454	0.0607	0.4873
455	0.0450	0.5029
456	0.0450	0.5170
457	0.0720	0.5085
458	0.0706	0.5000
459	0.0720	0.5142
460	0.0664	0.5226
461	0.0579	0.5269
462	0.0810	0.5353
463	0.0880	0.5466
464	0.0438	0.5424
465	0.0367	0.5382

(Concluded)

TABLE A VI

COORDINATES OF 1/2 INCH DIAMETER PARTICLES

FRAME NUMBER	X (ft)	Y (ft)	FRAME NUMBER	X (ft)	Y (ft)
85	0.1201	0.1424	85	0.1172	0.1526
86	0.1201	0.1424	86	0.1116	0.1582
87	0.1102	0.1744	87	0.1158	0.1639
88	0.1172	0.1746	88	0.1201	0.1526
89	0.1158	0.1594	89	0.1257	0.1469
90	0.1158	0.1594	90	0.1257	0.1469
91	0.1331	0.1752	91	0.1257	0.1469
92	0.0990	0.1752	92	0.1285	0.1384
93	0.0989	0.1610	93	0.1285	0.1384
94	0.1031	0.1594	94	0.1271	0.1455
95	0.0946	0.1439	95	0.1271	0.1610
96	0.0304	0.1695	96	0.1300	0.1539
97	0.0989	0.1723	97	0.1342	0.1681
98	0.0946	0.1439	98	0.1398	0.1723
99	0.0946	0.1539	99	0.1398	0.1522
100	0.0989	0.1723	100	0.1398	0.1822
101	0.1017	0.1723	101	0.1469	0.1822
102	0.1088	0.1582	102	0.1469	0.1922
103	0.1215	0.1610	103	0.1596	0.1922
104	0.1116	0.1808	104	0.1624	0.1809
105	0.1088	0.1936	105	0.1554	0.1723
106	0.1088	0.1965	106	0.1469	0.1624
107	0.1215	0.1794	107	0.1427	0.1568
108	0.1301	0.1766	108	0.1441	0.1624
109	0.1172	0.1737	109	0.1398	0.1540
110	0.1144	0.1780	110	0.1271	0.1526
111	0.1187	0.1695	111	0.1187	0.1582
112	0.1187	0.1695	112	0.1074	0.1695
113	0.1074	0.1737	113	0.1031	0.1709
114	0.1345	0.1766	114	0.1059	0.1639
115	0.1398	0.1610	115	0.1059	0.1639
116	0.1074	0.1540	116	0.0932	0.1752
117	0.0932	0.1639	117	0.0904	0.1794
118	0.0932	0.1639	118	0.1003	0.1695
119	0.0975	0.1526	119	0.1045	0.1639
120	0.1074	0.1540	120	0.0989	0.1681
121	0.1017	0.1610	121	0.1003	0.1695
122	0.0989	0.1695	122	0.1130	0.1780
123	0.0989	0.1695	123	0.1285	0.1709
124	0.1116	0.1540	124	0.1441	0.1639

(Continued)

TABLE AVI

COORDINATES OF 1/2 INCH DIAMETER PARTICLES

FRAME NUMBER	X (ft)	Y (ft)	FRAME NUMBER	X (ft)	Y (ft)
125	0.1504	0.1410	165	0.1709	0.1303
126	0.1569	0.1511	166	0.1667	0.1243
127	0.1511	0.1384	167	0.1667	0.1187
128	0.1427	0.1358	168	0.1667	0.1243
129	0.1511	0.1384	169	0.1554	0.1229
130	0.1526	0.1455	170	0.1497	0.1243
131	0.1511	0.1384	171	0.1427	0.1285
132	0.1540	0.1384	172	0.1384	0.1285
133	0.1424	0.1413	173	0.1328	0.1329
134	0.1481	0.1469	174	0.1300	0.1329
135	0.1554	0.1427	175	0.1215	0.1329
136	0.1540	0.1384	176	0.1158	0.1389
137	0.1554	0.1356	177	0.1045	0.1467
138	0.1582	0.1398	178	0.1017	0.1427
139	0.1582	0.1370	179	0.0932	0.1511
140	0.1540	0.1370	180	0.0848	0.1553
141	0.1526	0.1441	181	0.0862	0.1780
142	0.1424	0.1497	182	0.0848	0.1972
143	0.1424	0.1526	183	0.0833	0.1967
144	0.1596	0.1469	184	0.0791	0.2034
145	0.1596	0.1469	185	0.0777	0.2076
146	0.1424	0.1526	186	0.0777	0.2187
147	0.1667	0.1596	187	0.0876	0.2274
148	0.1554	0.1526	188	0.0989	0.2371
149	0.1427	0.1582	189	0.0961	0.2302
150	0.1328	0.1667	190	0.0890	0.2331
151	0.1328	0.1752	191	0.0961	0.2433
152	0.1356	0.1822	192	0.0946	0.2514
153	0.1427	0.1907	193	0.0932	0.2597
154	0.1554	0.1907	194	0.0862	0.2485
155	0.1723	0.1879	195	0.0862	0.2485
156	0.1808	0.1808	196	0.0946	0.2458
157	0.1836	0.1723	197	0.0946	0.2459
158	0.1836	0.1695	198	0.0932	0.2284
159	0.1779	0.1639	199	0.0946	0.2219
160	0.1850	0.1554	200	0.1074	0.2289
161	0.1794	0.1441	201	0.1215	0.2218
162	0.1737	0.1300	202	0.1130	0.2062
163	0.1766	0.1271	203	0.1130	0.1907
164	0.1922	0.1314	204	0.1187	0.1780

(Continued)

TABLE A VI

COORDINATES OF 1/2 INCH DIAMETER PARTICLES

FRAME NUMBER	X (ft)	Y (ft)	FRAME NUMBER	X (ft)	Y (ft)
204	0.1243	0.1424	245	0.1328	0.1610
206	0.1285	0.1568	246	0.1300	0.1447
207	0.1300	0.1610	247	0.1328	0.1709
208	0.1370	0.1624	248	0.1370	0.1582
209	0.1398	0.1568	249	0.1370	0.1582
210	0.1398	0.1554	250	0.1257	0.1639
211	0.1413	0.1582	251	0.1257	0.1850
212	0.1497	0.1639	252	0.1342	0.2034
213	0.1398	0.1568	253	0.1455	0.2147
214	0.1370	0.1596	410	0.0085	0.0720
215	0.1356	0.1511	411	0.0028	0.0678
216	0.1469	0.1511	412	-.0071	0.0749
217	0.1441	0.1419	413	-.0141	0.0735
218	0.1384	0.1441	414	-.0141	0.0692
219	0.1384	0.1441	415	-.0071	0.0650
220	0.1413	0.1582	416	-.0127	0.0749
221	0.1469	0.1681	417	-.0127	0.0720
222	0.1356	0.1695	418	-.0127	0.0720
223	0.1243	0.1752	419	-.0057	0.0622
224	0.1074	0.1838	420	-.0057	0.0622
225	0.0941	0.1865	421	-.0085	0.0678
226	0.0941	0.1838	422	-.0071	0.0622
227	0.0980	0.1766	423	-.0028	0.0537
228	0.0932	0.1752	424	-.0042	0.0593
229	0.0980	0.1695	425	-.0071	0.0664
230	0.0918	0.1610	426	-.0071	0.0720
231	0.0941	0.1540	427	-.0014	0.0720
232	0.0804	0.1582	428	0.0071	0.0692
233	0.0804	0.1582	429	0.0014	0.0819
234	0.0918	0.1610	430	0.0014	0.0819
235	0.0804	0.1582	431	0.0099	0.0749
236	0.0383	0.1439	432	0.0099	0.0622
237	0.0889	0.1721	433	0.0071	0.0551
238	0.1074	0.1794	434	-.0071	0.0579
239	0.1187	0.1721	435	-.0140	0.0509
240	0.1243	0.1695	436	-.0099	0.0438
241	0.1187	0.1723	437	-.0099	0.0396
242	0.1184	0.1766	438	-.0169	0.0367
243	0.1184	0.1709	439	-.0297	0.0396
244	0.1243	0.1639	440	-.0410	0.0396

(Continued)

TABLE A VI

COORDINATES OF 1/2 INCH DIAMETER PARTICLES

FRAME NUMBER	X (ft)	Y (ft)
441	-.0979	0.0410
442	-.0407	0.0509
443	-.0421	0.0607
444	-.0704	0.0607
445	-.0777	0.0434
446	-.0905	0.0720
447	-.0905	0.0868
448	-.0942	0.0479
449	-.1001	0.0833
450	-.1130	0.0949
451	-.1148	0.0961
452	-.1130	0.1086
453	-.1102	0.1285
454	-.1148	0.1154
455	-.1271	0.1324
456	-.1327	0.1241
457	-.1327	0.1329
458	-.1156	0.1384
459	-.1441	0.1114
460	-.1540	0.1257
461	-.1542	0.1241
462	-.1441	0.1314
463	-.1328	0.1342
464	-.1469	0.1271
465	-.1307	0.1201
466	-.1469	0.1187
467	-.1384	0.1187
468	-.1526	0.1114
469	-.1568	0.1130
470	-.1568	0.1130
471	-.1413	0.1158
472	-.1328	0.1130
473	-.1300	0.1102
474	-.1243	0.1059
475	-.1215	0.1059
476	-.1215	0.1059
477	-.1215	0.1059
478	-.1243	0.1059
479	-.1271	0.0904
480	-.1243	0.0819

FRAME NUMBER	X (ft)	Y (ft)
481	-.1243	0.0819
482	-.1356	0.0918
483	-.1356	0.0918
484	-.1328	0.0961
485	-.1413	0.0989
486	-.1526	0.1031
487	-.1540	0.1074
488	-.1441	0.1031
489	-.1413	0.0961
490	-.1497	0.0961
491	-.1526	0.1031
492	-.1497	0.0961
493	-.1441	0.0904
494	-.1526	0.0918
495	-.1497	0.0975
496	-.1356	0.0946
497	-.1300	0.0946
498	-.1384	0.0989
499	-.1469	0.1130
500	-.1441	0.1215
501	-.1384	0.1370
502	-.1384	0.1370
503	-.1483	0.1342
504	-.1511	0.1271
505	-.1427	0.1342
506	-.1384	0.1370
507	-.1511	0.1271
508	-.1568	0.1271
509	-.1568	0.1271
510	-.1483	0.1342
511	-.1568	0.1314
512	-.1596	0.1271
513	-.1568	0.1314
514	-.1427	0.1314
515	-.1441	0.1229
516	-.1568	0.1158
517	-.1511	0.1172
560	-.1003	0.1074
561	-.1045	0.1074
562	-.1172	0.1130

(Continued)

TABLE A VI

COORDINATES OF 1/2 INCH DIAMETER PARTICLES

FRAME NUMBER	X (ft)	Y (ft)	FRAME NUMBER	X (ft)	Y (ft)
563	-.1300	0.1130	603	-.1441	0.1215
564	-.1441	0.1172	604	-.1455	0.1187
565	-.1469	0.1243	605	-.1398	0.1144
566	-.1384	0.1328	606	-.1511	0.1088
567	-.1441	0.1329	607	-.1511	0.1088
568	-.1540	0.1384	608	-.1568	0.1088
569	-.1540	0.1427	609	-.1497	0.0989
570	-.1441	0.1540	610	-.1568	0.0932
571	-.1370	0.1540	611	-.1596	0.0989
572	-.1427	0.1469	612	-.1568	0.0932
573	-.1427	0.1469	613	-.1497	0.0833
574	-.1370	0.1540	614	-.1469	0.0962
575	-.1370	0.1540	615	-.1568	0.0932
576	-.1469	0.1526	616	-.1568	0.1031
577	-.1568	0.1497	617	-.1526	0.0989
578	-.1469	0.1624	618	-.1427	0.0975
579	-.1398	0.1639	619	-.1568	0.1074
580	-.1427	0.1596	620	-.1596	0.1130
581	-.1469	0.1525	621	-.1639	0.1257
582	-.1469	0.1568	622	-.1582	0.1370
583	-.1427	0.1639	623	-.1596	0.1413
584	-.1370	0.1667	624	-.1596	0.1469
585	-.1413	0.1610	625	-.1511	0.1511
586	-.1413	0.1610	626	-.1455	0.1596
587	-.1356	0.1639	627	-.1455	0.1639
588	-.1356	0.1639	628	-.1554	0.1596
589	-.1483	0.1540	629	-.1610	0.1554
590	-.1554	0.1455	630	-.1483	0.1624
591	-.1497	0.1497	631	-.1441	0.1610
592	-.1455	0.1413	632	-.1497	0.1455
593	-.1540	0.1300	633	-.1526	0.1370
594	-.1568	0.1201	634	-.1455	0.1384
595	-.1497	0.1130	635	-.1328	0.1342
596	-.1342	0.1158	636	-.1300	0.1257
597	-.1257	0.1158	637	-.1370	0.1130
598	-.1074	0.1172	638	-.1370	0.0989
599	-.1074	0.1229	639	-.1356	0.0791
600	-.1116	0.1342	640	-.1328	0.0720
601	-.1186	0.1342	641	-.1455	0.0791
602	-.1300	0.1314	642	-.1469	0.0819

(Continued)

TABLE A VI

COORDINATES OF 1/2 INCH DIAMETER PARTICLES

FRAME NUMBER	X (ft)	Y (ft)	FRAME NUMBER	X (ft)	Y (ft)
643	-.1413	0.0735	693	-.1271	0.1045
644	-.1356	0.0819	694	-.1356	0.1088
645	-.1526	0.0989	695	-.1413	0.1172
646	-.1526	0.1130	696	-.1356	0.1243
647	-.1455	0.1314	697	-.1271	0.1300
648	-.1370	0.1455	698	-.1300	0.1215
649	-.1370	0.1455	699	-.1356	0.1130
650	-.1483	0.1370	865	-.1497	0.1554
651	-.1483	0.1370	866	-.1526	0.1526
652	-.1356	0.1398	867	-.1413	0.1526
653	-.1229	0.1314	868	-.1370	0.1497
654	-.1229	0.1201	869	-.1455	0.1370
655	-.1257	0.1116	870	-.1554	0.1370
656	-.1300	0.0975	871	-.1540	0.1413
657	-.1342	0.0819	872	-.1455	0.1469
658	-.1483	0.0948	873	-.1497	0.1413
659	-.1526	0.0932	874	-.1540	0.1413
660	-.1483	0.0948	875	-.1497	0.1455
661	-.1483	0.0805	876	-.1384	0.1497
662	-.1510	0.0876	877	-.1384	0.1413
663	-.1582	0.0932	878	-.1540	0.1314
664	-.1582	0.0989	879	-.1582	0.1229
665	-.1455	0.0904	880	-.1582	0.1229
666	-.1455	0.0904	881	-.1526	0.1229
667	-.1526	0.1003	882	-.1568	0.1201
668	-.1526	0.1074	883	-.1540	0.1201
669	-.1413	0.1158	884	-.1455	0.1243
670	-.1257	0.1172	885	-.1271	0.1300
671	-.1271	0.1116	886	-.1271	0.1229
672	-.1243	0.1130	887	-.1328	0.1172
673	-.1201	0.1172	888	-.1328	0.1172
674	-.1144	0.1187	889	-.1144	0.1229
675	-.1074	0.1116	890	-.1144	0.1229
676	-.1017	0.1045	891	-.1116	0.1144
677	-.1031	0.0918	892	-.1144	0.1088
678	-.1186	0.0805	893	-.1172	0.1059
679	-.1271	0.0833	894	-.1243	0.1088
680	-.1413	0.0932	895	-.1384	0.1088
681	-.1455	0.1045	896	-.1427	0.1144
682	-.1356	0.1031	897	-.1384	0.1271

(Continued)

TABLE A VI

COORDINATES OF 1/2 INCH DIAMETER PARTICLES

FRAME NUMBER	X (ft)	Y (ft)	FRAME NUMBER	X (ft)	Y (ft)
898	-.1314	0.1314	1158	-.1554	0.1427
899	-.1384	0.1271	1159	-.1469	0.1427
900	-.1314	0.1243	1160	-.1398	0.1427
901	-.1243	0.1314	1161	-.1427	0.1342
902	-.1243	0.1314	1162	-.1497	0.1215
903	-.1314	0.1271	1163	-.1511	0.1102
904	-.1384	0.1271	1164	-.1427	0.0989
905	-.1271	0.1356	1165	-.1328	0.0932
906	-.1271	0.1356	1166	-.1427	0.0989
907	-.1497	0.1271	1167	-.1427	0.0989
908	-.1554	0.1271	1168	-.1356	0.1045
909	-.1526	0.1356	1169	-.1314	0.1074
910	-.1356	0.1356	1170	-.1441	0.1144
911	-.1384	0.1257	1171	-.1497	0.1201
912	-.1413	0.1172	1172	-.1413	0.1342
913	-.1356	0.1144	1173	-.1370	0.1370
914	-.1186	0.1116	1174	-.1413	0.1342
915	-.1102	0.1031	1175	-.1497	0.1314
916	-.0960	0.0975	1176	-.1554	0.1328
917	-.0960	0.0975	1177	-.1427	0.1398
918	-.1088	0.0976	1178	-.1342	0.1328
919	-.1201	0.0919	1179	-.1497	0.1314
920	-.1314	0.0848	1180	-.1469	0.1271
921	-.1413	0.0904	1181	-.1370	0.1370
922	-.1455	0.0976	1182	-.1314	0.1483
923	-.1455	0.0976	1183	-.1427	0.1483
1144	-.1540	0.0819	1184	-.1469	0.1427
1145	-.1596	0.0975	1185	-.1384	0.1540
1146	-.1639	0.1102	1186	-.1384	0.1582
1147	-.1540	0.1088	1187	-.1455	0.1554
1148	-.1639	0.1102	1188	-.1610	0.1554
1149	-.1639	0.1102	1189	-.1582	0.1653
1150	-.1639	0.1201	1190	-.1497	0.1737
1151	-.1568	0.1257	1191	-.1511	0.1865
1152	-.1526	0.1285	1192	-.1596	0.1865
1153	-.1596	0.1300	1193	-.1582	0.1836
1154	-.1610	0.1328	1194	-.1483	0.1794
1155	-.1497	0.1455	1195	-.1441	0.1695
1156	-.1455	0.1540	1196	-.1540	0.1554
1157	-.1540	0.1497	1197	-.1568	0.1483

(Continued)

TABLE A VI

COORDINATES OF 1/2 INCH DIAMETER PARTICLES

FRAME NUMBER	X (ft)	Y (ft)	FRAME NUMBER	X (ft)	Y (ft)
1198	-.1469	0.1526	1238	-.2769	0.0381
1199	-.1413	0.1455	1239	-.2853	0.0466
1200	-.1511	0.1384	1240	-.2910	0.0466
1201	-.1511	0.1329	1241	-.2966	0.0565
1202	-.1413	0.1356	1242	-.3051	0.0650
1203	-.1427	0.1271	1243	-.3192	0.0791
1204	-.1329	0.1243	1244	-.3249	0.0919
1205	-.1441	0.1187	1245	-.3221	0.0975
1206	-.1441	0.1158	1246	-.3108	0.0904
1207	-.1300	0.1116	1247	-.3150	0.0946
1208	-.1186	0.1045	1248	-.3150	0.0989
1209	-.1059	0.0989	1249	-.3108	0.1045
1210	-.1017	0.0946	1250	-.2952	0.1017
1211	-.1144	0.0833	1251	-.2924	0.1017
1212	-.1243	0.0777	1252	-.3023	0.1102
1213	-.1384	0.0833	1253	-.3051	0.1074
1214	-.1469	0.0904	1254	-.3009	0.1003
1215	-.1469	0.0904	1255	-.2910	0.0961
1216	-.1469	0.0904	1256	-.3023	0.1045
1217	-.1582	0.1003	1257	-.2980	0.1158
1218	-.1639	0.1031	1258	-.2910	0.1314
1219	-.1681	0.1074	1259	-.2769	0.1427
1220	-.1624	0.0989	1260	-.2670	0.1370
1221	-.1723	0.0975	1261	-.2627	0.1215
1222	-.1780	0.1003	1262	-.2656	0.1257
1223	-.1822	0.1031	1263	-.2656	0.1257
1224	-.1865	0.1074	1264	-.2627	0.1215
1225	-.1978	0.1045	1265	-.2627	0.1130
1226	-.2034	0.1031	1266	-.2740	0.1059
1227	-.2133	0.1003	1267	-.2797	0.1017
1228	-.2204	0.0961	1268	-.2881	0.1059
1229	-.2260	0.0948	1269	-.3079	0.1130
1230	-.2288	0.0919	1270	-.3093	0.1187
1231	-.2359	0.0706	1271	-.3009	0.1328
1232	-.2486	0.0509	1272	-.2896	0.1427
1233	-.2514	0.0424	1273	-.2952	0.1455
1234	-.2542	0.0396	1274	-.3037	0.1483
1235	-.2514	0.0424	1275	-.3009	0.1582
1236	-.2627	0.0381	1276	-.3009	0.1667
1237	-.2712	0.0367	1277	-.2980	0.1794

(Continued)

TABLE A VI

COORDINATES OF 1/2 INCH DIAMETER PARTICLES

FRAME NUMBER	X (ft)	Y (ft)	FRAME NUMBER	X (ft)	Y (ft)
1278	-.3037	0.1752	1298	-.2175	0.1992
1279	-.2867	0.1908	1299	-.2062	0.2062
1280	-.2740	0.1965	1300	-.2006	0.2020
1281	-.2627	0.1907	1301	-.2119	0.1949
1282	-.2486	0.1949	1302	-.2119	0.1865
1283	-.2401	0.1978	1303	-.2034	0.1723
1284	-.2359	0.2062	1304	-.1921	0.1610
1285	-.2288	0.2133	1305	-.1822	0.1624
1286	-.2218	0.2246	1306	-.1822	0.1695
1287	-.2175	0.2218	1307	-.1822	0.1653
1288	-.2260	0.2119	1308	-.1822	0.1610
1289	-.2288	0.2062	1309	-.1766	0.1596
1290	-.2260	0.2119	1310	-.1526	0.1653
1291	-.2260	0.2119	1311	-.1469	0.1695
1292	-.2316	0.2090	1312	-.1554	0.1568
1293	-.2316	0.2090	1313	-.1554	0.1568
1294	-.2218	0.2175	1314	-.1483	0.1624
1295	-.2175	0.2288	1315	-.1413	0.1610
1296	-.2175	0.2175	1316	-.1497	0.1511
1297	-.2218	0.2105	1317	-.1554	0.1483

(Concluded)